PROCEEDINGS OF THE ROYAL INSTITUTION OF GREAT BRITAIN

Vol. 38 Part IV No. 173
1961

Containing accounts of the
FRIDAY EVENING DISCOURSES
and other meetings

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Proceedings of the

GENERAL MONTHLY MEETINGS

of the

Members of the Royal Institution

held during 1960

and the

Annual Meeting 1960

Printed as an inset to

PROCEEDINGS OF THE ROYAL INSTITUTION, 1961

Vol. 38 Part IV No. 173

GENERAL MONTHLY MEETING

Monday, 1 February 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.
President, in the Chair

C. R. Bedwell
D. W. Cushen
Miss K. N. H. Harker
L. D. Hewitt
Dr. D. W. Holder
J. McCarthy
Dr. G. J. Minkoff
Miss M. R. Sellers
W. S. Stiles
K. K. Terry

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

P. M. Coursey
A. C. Hartley
Miss Lilian Quartly
Lady Thornycroft
H. Hawkins Turner
Miss M. D. Waller

The Chairman reported that the Managers had elected the following:—

ASSOCIATE SUBSCRIBER

Mrs. C. M. Cromwell Stephens

CORPORATE SUBSCRIBERS

British Titan Products Co., Ltd.
British Xylonite Co., Ltd.
Laporte Industries, Ltd.

LIBRARY SUBSCRIBERS

J. Fagbemi
Dr. J. A. Newell
I. F. Rolls

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

Anchor Books (*Doubleday & Co. Inc.*)—Birth of a new physics, by I. Bernard Cohen. 1960.

Central Office of Information—Britain 1960.

J. G. Crowther, M.R.I.—Rudolf Diesel and Burmeister and Wain, by J. Lehmann. 1938.

CIBA Ltd.—The story of the chemical industry in Basle. 1959.

E. Ironmonger, M.R.I.—The correspondence of Isaac Newton. Vol. 1. 1959.

Mrs. A. W. Isenthal—10 books on radiation physics and radio-telephony from the library of the late A. W. Isenthal.

Frank Rumford—Chemical engineering materials, by Frank Rumford. 2nd. ed. 1960.

Shell International Petroleum Co.—Petroleum handbook. 4th ed. 1959.

GENERAL MONTHLY MEETING

Monday, 7 March 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.

President, in the Chair

Dr. G. L. Asherson
Dr. H. J. B. Atkins
L. Bagrit
Miss A. Balthazal
J. S. Ewins
E. H. Forrester
J. V. Hamilton
Miss C. Moore-Brabazon
Dr. W. H. Parkinson
H. E. Robson
C. E. Surman

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

Major W. H. Cadman
C. Cooper
R. M. Hyslop

The Chairman reported that the Managers had elected the following:—

ASSOCIATE SUBSCRIBERS

R. K. Innes
E. M. Reeves

CORPORATE SUBSCRIBERS

Distillers Co., Ltd.
Ilford, Ltd.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

A. G. Gaydon, D.Sc., F.R.S., M.R.I.—Flames: their structure, radiation and temperature, by A. G. Gaydon and H. G. Wolfhard. 1960.

National Physical Laboratory—The physical chemistry of metallic solutions. 2 vols. 1959.

H. R. Rishworth, C.B.E., F.R.C.S., M.R.I.—11 volumes on mathematics, astronomy and other subjects.

Professor Jean Timmermans, Hon. M.R.I.—Physico-chemical constants of binary systems, by J. Timmermans. Vol. 2. 1959.

GENERAL MONTHLY MEETING

Monday, 4 April 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.

President, in the Chair

Dr. A. A. Black
Dr. I. D. Brown
H. L. J. Burgess
B. R. Byrne
G. E. Caraker
Miss J. Dobson
M. J. Duell
R. H. Morris
R. M. Poulter
Dr. L. P. Williams
E. J. Wiseman

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Chairman announced the decease of the following:—

V. Blagden
Countess de Chrapowicki
C. W. Hartmann
Mrs. Margot A. Holmes
S. Robson

MR. STANLEY ROBSON

Lord Brabazon referred to the death of Mr. Stanley Robson and said that the Institution had indeed lost a great friend who had served it well as Secretary during a most difficult time. He paid tribute to Mr. Robson's qualities saying how much he was loved by all the Members and how sadly he would be missed.

The Chairman reported that the Managers had elected the following:—

ASSOCIATE SUBSCRIBER

M. Warrington

LIBRARY SUBSCRIBERS

K. I. Dobson
J. M. Ogborn

NOMINATION OF PROFESSORS

The Chairman gave notice that the Managers had nominated Professor Ronald King, B.Sc., Ph.D. as Professor of Metal Physics, and Professor R. S. Nyholm, D.Sc., Ph.D., F.R.S. as Professor of Natural Philosophy, for election at the next General Monthly Meeting.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

J. Home Dickson, M.Sc., M.R.I.—Laboratory instruments, by A. Elliott and J. Home Dickson. 2nd ed. 1959.

Linus C. Pauling, Hon. M.R.I.—Nature of the chemical bond, by Linus Pauling. 3rd ed. 1960.

Pergamon Press—Low temperature physics, by F. E. Simon and others.

Professor Jean Timmermans, Hon. M.R.I.—Physico-chemical constants of binary systems, by J. Timmermans. Vol. 3. 1960.

U.S. Information Service, American Library—17 volumes on various scientific subjects.

ANNUAL MEETING

Monday, 2 May 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.

President, in the Chair

The Annual Report of the Committee of Visitors and the Statement of Accounts for the year 1959 were presented by the Chairman of the Visitors, Dr. P. C. Spensley, who drew attention to two particular points which the Committee of Visitors wished to commend most strongly: (a) the very substantial increase in the number of Corporate Subscribers and the consequent favourable development in the Institution's finances, and (b) Sir Lawrence Bragg's continued success with the Schools Lectures and his talks on the B.B.C. Television.

The Treasurer referred to the formation of the Investments Pool and pointed out that credit must be given to Dr. Schulman, a former Manager, who had suggested its formation.

It was resolved that the Annual Report of the Visitors and the Statement of Accounts for the year 1959 be approved and adopted. (The Report is published in full in the *Record of the Royal Institution* 1960).

Sir Lawrence Bragg presented his Report for the year 1959 and referred to the Schools Lectures, particularly the staging of experiments by Mr. Coates; the building up of the collection of apparatus for the use of science teachers; the television lectures, which had

meant so much extra work for the staff; the introduction of the scheme for Reader's Tickets which enabled non-Members to make use of the Library. He also referred to the research work and the support now given by the National Institutes of Health in America and by the Medical Research Council.

The following were elected Officers for the ensuing year:—

President—The Right Hon. Lord Brabazon of Tara, G.B.E., M.C., P.C.

Treasurer—W. E. Schall, B.Sc., F.Inst.P.

Secretary—Sir Harold Spencer Jones, K.B.E., Sc.D., F.R.S.

Managers

T. E. Allibone, D.Sc., Ph.D., F.R.S.
H. D. Anthony, M.A., B.Sc., Ph.D.
F. G. Brown
E. R. Davies, O.B.E., B.Sc., F.Inst.P.
A. G. Gaydon, D.Sc., F.R.S.
H. Heywood, D.Sc., Ph.D.
Mrs. H. K. Hawkes, M.Sc., F.G.S.
R. Holroyd, M.Sc., Ph.D., F.R.S.
Brigadier H. E. Hopthrow, C.B.E., M.I.Mech.E.
L. B. W. Jolley, M.A., M.I.E.E.
Professor L. A. Jordan, C.B.E., D.Sc., F.R.I.C.
Sir Ben Lockspeiser, K.C.B., D.Sc., F.R.S.
P. H. Schwarzschild
Wing Commander H. F. Tiarks, F.R.A.S.
Professor W. D. Wright, D.Sc., D.I.C., A.R.C.S.

Visitors

A. D. Baynes-Cope, M.A., B.Sc., F.R.S.A.I.
A. D. R. Caroe, M.A., F.R.I.B.A.
A. H. Ewen, M.A.
D. H. Follett, M.A., Ph.D., F.Inst.P.
G. J. Gollin, M.A., F.Inst.F., M.I.Mech.E.
S. Rees Jones, M.Sc., F.Inst.P.
W. C. Lister, B.Sc., M.I.E.E., F.Inst.P.
Miss C. M. McDowell, Ph.D.
Mrs. J. E. Milton, B.Sc.
F. Allen Mitchell
N. P. W. Moore, B.Sc., D.I.C.
A. A. Moss, B.Sc., Ph.D., F.S.A.
J. D. Peattie, C.B.E., B.Sc., M.I.E.E.
F. Y. Poynton, M.Sc., F.Inst.P.
Miss D. Sidebottom

GENERAL MONTHLY MEETING

Monday, 9 May 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.
President, in the Chair

J. L. Harrington Miss V. McIlwain
Brigadier F. Pocock

were elected Members of the Royal Institution.

ELECTION OF PROFESSORS

In accordance with the nominations made at the previous Meeting, Professor R. King, B.Sc., Ph.D. was re-elected Professor of Metal Physics, and Professor R. S. Nyholm, D.Sc., Ph.D., F.R.S. was elected Professor of Natural Philosophy.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

Max von Laue, *Honorary Member*
A. C. Mellor

VICE-PRESIDENTS FOR 1960–61

The President announced that he had appointed the following Managers to serve in the office of Vice-President for the year 1960–61:

Mr. E. R. Davies
Dr. H. Holroyd
Brigadier H. E. Hopthrow
Mr. L. B. W. Jolley
Sir Ben Lockspeiser
Mr. P. H. Schwarzschild
Mr. W. E. Schall, *Treasurer*
Sir Harold Spencer Jones, *Secretary*

PRESENTS TO THE LIBRARY

The presents received since the last meeting were laid on the table and the thanks of the Members returned for the same:—

A. L. Bacharach—Principles and practice of chromatography, by L. Zechmeister and L. Cholnoky. 1941.

Bern Dibner—10 volumes published by the Burndy Library.

English Universities Press—The world around us, ed. by Sir Graham Sutton. 1960.

GENERAL MONTHLY MEETING

Monday, 30 May 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.
President, in the Chair

P. B. Grose Harry Hanks
Professor A. V. Hill

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Member:—

Mrs. D. McNab Riddel

VICE-PRESIDENTS FOR 1960–61

The Chairman announced that he had appointed the following additional Managers to serve in the office of Vice-President for the year 1960–61:—

Dr. H. D. Anthony
Professor L. A. Jordan

The Chairman reported that the Managers had elected the following:—

ASSOCIATE SUBSCRIBER

Miss Judith Foster

DONATION

An anonymous donation of £50 had been received.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

Professor G. F. J. Garlick, Ph.D., D.Sc.—Luminescence, by G. F. J. Garlick. 1958.

Mrs. E. C. Richardson, M.R.I.—Eight books on genetics and other subjects.

G. A. Williams, M.R.I.—Quartz crystals for electrical circuits, by R. A. Heising. 1947.

GENERAL MONTHLY MEETING

Monday, 4 July 1960

W. E. SCHALL, B.Sc., F.Inst.P.
Treasurer and Vice-President, in the Chair

Professor E. Amaldi
Dr. D. W. Bronk
Academician W. A. Engelhardt
Professor M. Florkin
Professor W. Heisenberg
Professor N. E. Norlund
Professor J. H. Oort
Professor S. Rosseland
Academician I. M. Vinogradov
Professor J. Wyart
Professor S. O. Horstadius

were elected Honorary Members of the Royal Institution.

W. A. Hodges B. M. Jones

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Chairman announced the decease of the following Members:—

H. G. Gillespie
Arthur Holland
Robert Nelson
Dr. R. K. Schofield

The Chairman reported that the Managers had elected the following:—

ASSOCIATE SUBSCRIBER

R. A. Klein

CORPORATE SUBSCRIBER

Birfield, Ltd.

LIBRARY SUBSCRIBER

Michael Nelkon

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

R. J. Cross, M.R.I.—Thermodynamics of alloys, by J. Lumsden. 1952.

Propylaen-Verlag—Fortschritte der naturwissenschaft im 19 Jahrhundert, by Walter Gerlach. 1960.

GENERAL MONTHLY MEETING

Monday, 3 October 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.
President, in the Chair

H.R.H. The Duke of Edinburgh

was elected an Honorary Member

W. A. Evans
W. Padley

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

Mrs. J. R. Alderson
Mrs. A. Chaston Chapman
L. Dale
Sir Arthur Fleming
F. W. Stevenson
Dr. J. West
S. E. Phillips (Library Subscriber)

The Chairman reported that the Managers had elected the following:—

ASSOCIATE SUBSCRIBERS

Mrs. M. M. Acland
Miss M. J. Baker
Mrs. G. I. Harper
A. H. Laird
Miss J. F. Manning
Miss S. Maries
A. W. L. Morris
E. C. Morris
Mrs. K. A. Sully
Miss M. B. Tungay
S. Wentworth

CORPORATE SUBSCRIBERS

Darwins Group Ltd.
Metal Box Co., Ltd.
Muirhead & Co., Ltd.

GIFT AND DONATION

The Chairman reported the following:—

Gift from the late H. G. Gillespie of a magnetic tape recorder by Scophany & Baird and a bronze plaque of himself in uniform.

Donation of 25 guineas from the Taylor Woodrow Charity Trust.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

Dr. H. D. Anthony, M.R.I.—Sir Isaac Newton, by H. D. Anthony. 1960.

C. M. Cade, M.R.I.—Infra-red radar. 1960.

From the Exhibition of Soviet Books and Periodicals in London 1960—(1) Humphry Davy, by B. Mogilevsky. 1958. (2) La vie dans l'univers, by A. Oparine and V. Fessenkov. 1958. (3) Meteors, by V. Fedynsky. 1959.

J. W. Gruber—A conscience in conflict: the life of St. George Jackson Mivart, by J. W. Gruber. 1960.

Mrs. Rachel M. Hunt—Catalogue of botanical books in the Hunt Botanica Library. Vol. 1. 1958.

E. Ironmonger, M.R.I.—The correspondence of Isaac Newton, ed. by H. W. Turnbull. Vol. 2. 1960.

Geoffrey Parr, M.R.I.—(1) An account of Sir Isaac Newton's philosophical discoveries, by Colin Maclaurin, 1st ed. 1748. (2) Stained glass as an art. by Henry Holiday. 1896.

Rathbone Books—Science: chemistry, physics, astronomy, ed. by J. Bronowski. 1960.

H. R. Rishworth, C.B.E., M.R.I.—Genealogy of the Pepys family, by W. C. Pepys. 1960.

The late Stanley Robson, M.R.I.—Brief account of Bryan Donkin, F.R.S. and of the company he founded 150 years ago. 1953.

The Director, Science Museum—The aeroplane, by C. H. Gibbs-Smith. 1960.

GENERAL MONTHLY MEETING

Monday, 7 November 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.

President, in the Chair

SIR HAROLD SPENCER JONES

Lord Brabazon said "We are met together today under a cloud of sorrow at the sudden passing of our dear Secretary, Sir Harold Spencer Jones. It is not for me here to elaborate on his remarkable achieve-

ments in his own sphere of astronomy, but it was unanimously acknowledged that he was a great man.

We were indeed lucky in that he consented to become our Secretary and we at the Institution have all been conscious that we had serving us a very capable man of great wisdom, and his loss here will be keenly felt.

He leaves behind him for us all the fragrant memory of a great man, yet one of simplicity and kindness, who for us to know was to love, and we are all the poorer for his passing."

ELECTION OF MEMBERS

F. A. Askew
C. B. Davies
A. K. Godden
M. A. Hassid
J. C. de C. Henderson
A. C. Leyton
P. C. Scriven
W. W. Shadforth
Lt. Col. T. M. Simmons
W. A. Spofforth
Dr. E. G. Steward
Mrs. J. Twilley
Miss P. R. Wakeling
A. H. Willoughby

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Chairman announced the decease of the following Members:—

T. W. G. Acland
L. J. P. Maas
Miss N. Moller
A. A. Nove
Sir Cecil Weir

The Chairman announced that the Managers had elected the following:—

ASSOCIATE SUBSCRIBERS

Miss B. C. Burke
Mrs. E. S. Candlin
E. A. Eborall
Mrs. A. C. E. McCarthy
F. J. McLoughlin
Miss V. F. Murrell
J. H. Webb

CORPORATE SUBSCRIBER

Shell Chemical Co., Ltd.

OVERDRAFT AT BANK

The Treasurer said that at the present time there was a sufficient balance on the General Account, but in accordance with the Bye-laws he wished to ask Members for authorisation to continue to overdraw up to £5000 at Drummonds Bank until 31 December 1961.

This was agreed subject to confirmation at the next General Monthly Meeting.

PRESENTS TO THE LIBRARY

The presents received since the last Meeting were laid on the table and the thanks of the Members returned for the same:—

E. Ironmonger, M.R.I.—(1) The Artizan 1856–8. 2 vols. (2) The London Encyclopaedia. 22 vols. 1829.

A. E. E. McKenzie—The major achievements of science, by A. E. E. McKenzie. 2 vols. 1960.

H. R. Rishworth, C.B.E., M.R.I.—The complete herbal, by Nicholas Culpeper. 1843.

Cyril S. Smith—A history of metallography, by Cyril S. Smith. 1960.

Harry Sootin—Michael Faraday: from errand boy to master physicist, by Harry Sootin. 1960.

Trans-Antarctic Expedition Committee—Trans-Antarctic Expedition Scientific Reports nos. 2, 3 and 4. 1960.

GENERAL MONTHLY MEETING

Monday, 5 December 1960

THE RIGHT HON. LORD BRABAZON OF TARA, G.B.E., M.C., P.C.

President, in the Chair

A. J. Butler
Mrs. M. E. Butler
Miss Letitia Chitty
Colonel J. A. Davies
L. R. Leworthy
Dr. E. M. Reeves
Dr. A. F. Schavo

were elected Members of the Royal Institution.

MEMBERS DECEASED

The Secretary announced the decease of the following Members:—

W. H. Beckingham
Sir Robert Bland Bird
Lady Wrenbury

The Chairman reported that the Managers had elected the following:—

ASSOCIATE SUBSCRIBERS

Miss Veronica C. Bradley
Miss Diana Buirski
G. W. Childs
Miss Joan Greaves
Miss Jennifer McKay
Miss Patricia A. M. Madigan

CORPORATE SUBSCRIBER

Unilever, Ltd.

OVERDRAFT AT BANK

The Chairman proposed the confirmation of the resolution passed at the previous meeting to allow an overdraft up to £5000 at Drummonds Bank until 31 December 1961.

This was agreed.

ELECTION OF SECRETARY

Brigadier H. E. Hopthrow, having been duly balloted for, was elected as Secretary.

VACANCY FOR A MANAGER

The Chairman declared a vacancy for a Manager as a result of the election of Brigadier Hopthrow as Secretary.

EYES, COLOURS AND SHAPES

By J. Z. YOUNG, M.A., F.R.S.
Fullerian Professor of Physiology, the Royal Institution;
Professor of Anatomy, University College, London

Weekly Evening Meeting, Friday 19th February, 1960

P. H. Schwarzschild
Vice-President, in the Chair

THE responses that organisms make to light are fundamental for the continuation of life. The fact that we can speak in this way of "responses" shows at once that these processes, like all those of living organisms, have in a sense a different character from reactions of non-living systems. They have been selected because they contribute to the continuation of the organisms as self-maintaining systems.

Thus plants have come to contain their chlorophyll systems, which in light of certain wave-lengths make possible reactions that can only proceed if energy is made available. For animals, parasitic as it were on the plants, light is not itself a source of energy but a clue, important because it keeps them in adequate relations with the plants and other environmental factors. Animals must therefore make appropriate reactions to whatever changes in the light flux may be relevant for the maintenance of their lives. The sensitivity of animals to light also depends upon photochemical changes in pigments. The reactions set up are important, however, not because they yield energy but because they initiate patterns of nervous activity that can serve to produce appropriate reactions by the muscles. We are interested, therefore, not only in the photochemical mechanisms as such, but in the way that their effects are used to produce particular responses to certain features of the environment. We can say that this occurs because it is arranged that certain changes in the light produce signals in an appropriate code in the nervous system, which when decoded, initiate suitable actions. To take a very simple example, a sudden increase of light intensity is followed by narrowing of the pupil. This is ensured because certain cells in the retina discharge nerve impulses when the light brightens and these nerve fibres are connected to the motor nerve cells that activate the muscles of the iris. The "coding" in this case is

secured by the simple fact that cells that discharge when the light increases are connected to certain motor cells. No doubt the number and frequency of impulses generated also signals the amount of change.

The question of how the nervous system generates signals appropriate to a variety of changes around it has not been fully solved. Like any other code system it operates by using a limited number of physical states to indicate the occurrence of certain of the changes in the world around. We can illustrate this by examining what features of change in illumination can be detected by organisms and the signalling system by which this is done.

Light can vary in many ways, which the physicist calls intensity, wavelength, pattern of distribution, direction of electric vector and so on. Many organisms can respond to some or all of such changes but each organism measures only some aspects of the change in illumination. Thus man can make certain estimates of light intensity ("brighter", "darker"); he can name some colours, and make statements about some visual shapes that are 'significant' while neglecting others. He is unable to judge the direction of polarisation of light, as some other animals are able to do.

Intensity discrimination

Many animals react in such a way as to maintain themselves in an optimum position in relation to plants. Thus diurnal movements of plankton are partly light-controlled. Flatworms and many other animals move to the brighter or darker part of the field by means of phototropisms. Such animals could be said to have nervous systems that measure light intensity. They may perhaps also react somewhat differently to various wavelengths but be quite unable to make distinct reactions to different visual patterns.

Man is not greatly concerned with measuring the absolute level of brightness. But he is quite good at recognizing whether the light is becoming stronger or weaker, this information being useful in many ways. Even more important is the great power that man has of adjusting the eye so that it gives the maximum of information over a range of light intensity of perhaps a

thousand million times, between the light of the faintest star and the midday sun. When light is dim we can detect the faintest glimmer; when it is bright we are not blinded and can recognize minute differences of pattern.

In order to cover this range the eye has, of course, two distinct parts, the central fovea of cones for day vision and the peripheral zone of more sensitive rods for use at night. The basic photochemical event, at least in the rods, is the breakdown of the carotenoid pigment rhodopsin (visual purple), in the light and its resynthesis in the dark. It used to be held that the change during dark adaptation was simply this resynthesis and the reverse in the no less important light adaptation. But Rushton & Campbell have recently shown that bleaching only 2% of rhodopsin causes a rise of fifty times in threshold. That is to say, we are not blinded by the light although plenty of pigment is still there. Even at quite strong illumination only 10% is bleached.

This and other evidence is interpreted as showing that accommodation is not wholly a simple physico-chemical change, but is at least partly due to changes in the nervous signals that are set up. This must presumably depend upon alterations in the synaptic connections in the retina. The connections of the various types of cell probably varies with the brightness. When there is little light many rods summate and produce impulses in the larger ganglion cells, whose firing activates those brain centres that record the occurrence of faint glimmers; however, in this condition little discrimination of points is possible. When there is more light other cells and pathways become activated; neighbouring illuminated regions now inhibit each other and only contours are important, so that shapes and fine detail can be recorded. The minute amacrine cells, with short branches, may well serve this function of lateral inhibition, increasing the effects of edges.

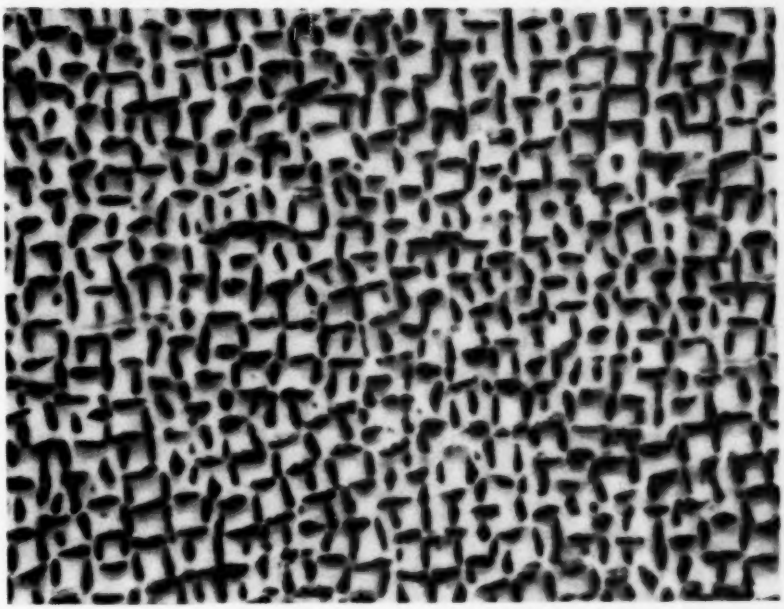
As Barlow puts it, the retina is so constructed as to make the maximum possible use of the information contained in the light entering the eye. At all levels of intensity this approaches the limit that is set by quantal fluctuations. We might put it that in darkness we can see when there is almost no light and at great brightness we can discriminate almost no distance.

Colour discrimination

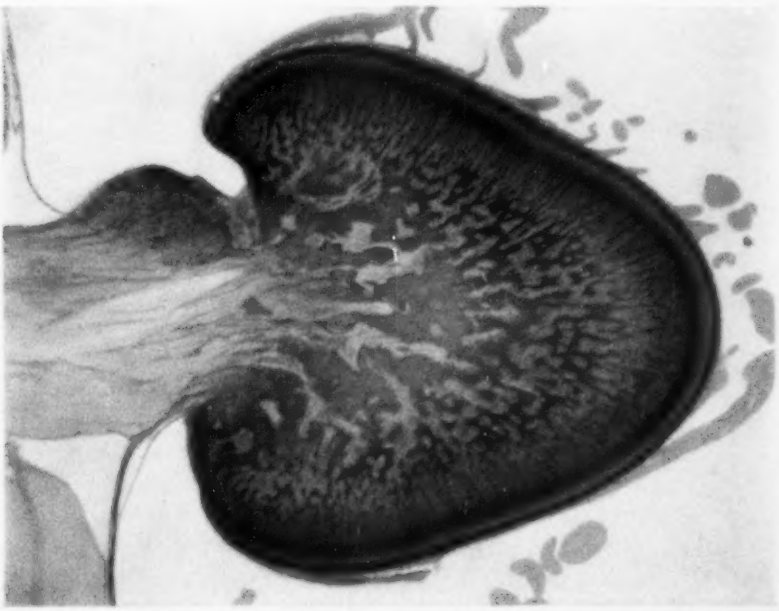
The fact that we distinguish colours means that in a sense our eyes and brain measure the wavelength of light. But we do not give the results as a physicist does in millimicrons. We give it in the form of a series of names, i.e. "colours". This may be a useful example of how coding systems have evolved. Our retinas and our language have so developed that we pick out certain steps within the continuous series of the spectrum and name them as colours. The system is arranged, according to Thomas Young's three-colour theory, around detectors for three 'primary' wavelengths—red, green and blue. May not this be because these are of special importance to us? Red of blood and fire, green of plants and blue of sea and sky, and so on. By combinations of these three types of receptors we can identify the wavelengths reflected from leaves, fruit and meats, and tell whether they are good or bad. We can record the appearances of our companions, foretell the state of the weather and make many other useful predictions.

The point is that a proper consideration of colour vision, as of any other "sensory" process, should go hand in hand with the study of the use the animal or man makes of its powers and indeed of the colours that it produces on its own body, whether for protection, warning or communication with other members of the species. It is, I believe, a general principle of those who try to 'break' codes to find out what sorts of facts the code deals with. Similarly, we shall only see the relevant features of the living code system when we consider not only the receptor end and the process of coding, but the decoding as well, and hence the use made of the whole signalling system.

The system of identifying certain ranges of wavelengths is almost certainly determined by the presence of detectors with maximum sensitivity at certain wavelengths. The way that these are combined and used is probably determined partly by heredity, partly by a process of learning. Hartline, Granit and others have made some progress in distinguishing between the detectors, but much remains obscure. Many kinds of interaction must occur in the retina and further along the visual pathway to produce the results that follow from stimulating the eye with various mixtures of wavelengths. The eye and brain together



A. Section parallel to the surface of the retina of an octopus. Each large black oval is the cell body of a retinal cell and many of these are associated in fours to make 'rhabdomes'. The long axis of the photograph is in the horizontal plane of the animal.



B. Section parallel to the surface of the optic lobe of an octopus, stained with Cajal's silver method. All the longer fibres are stained and they run predominantly in horizontal and vertical directions. The long axis of the photograph is horizontal.

PLATE I

make judgments that do not depend only on the wavelength—for example in judging colour we partly disregard the illuminant wavelength. Land has recently called attention to the fact that the colours reported from objects do not by any means agree with what one would expect by rigid application of the 'classical' tristimulus hypothesis. This was known already to Helmholtz in the nineteenth century but has often been forgotten in the enthusiasm for 'scientific' study of vision by means of points of monochromatic light. Unfortunately, such points are rarely present in nature and the eye and brain are designed to provide useful information about the complicated combinations of reflected light that do occur.

How these combined effects are produced remains obscure. In the centre of the fovea every cone is connected with a single midget bipolar cell and it is usual to stress the independence of these pathways. Even in the fovea, however, the network provides many opportunities for interaction, such as the giant multipolar cells. The effects of stimulation of receptors with different maximum sensitivities are probably made to interact either at this level or further centrally. The arrangement that constitutes the coding system is probably produced mainly by heredity, but may also be influenced by learning.

Form discrimination

For us the most interesting and important of all uses of the eyes is to detect the *pattern* of distribution of light and colour before us, that is to say the *shape* of objects. This is no doubt valuable enough for all primates but in modern man acquires its special importance by the capacity it gives to read, that is to consult the common store of information that is available for all who wish to use it.

There is as yet surprisingly little understanding of how the eye and brain encode, transmit and decode this sort of information. Study of response to flashes of light is not likely to provide useful clues. By recording the nerve impulses set up in the frog's optic nerve by somewhat more complex stimuli Lettvin, Maturana, McCulloch and Pitts have shown that certain forms likely to be frequently encountered are "recognized" by exciting particular retinal cells. Thus a small curved object

entering the visual field and staying there fires one type of cell, which may be called a "fly detector". These cells are not fired by straight moving edges, but there is another type that does respond to these. A third set of cells responds to general darkening. The suggestion is that the various cells are detectors of situations that are specifically important for a frog, such as the appearance of a fly or the shadow cast by the passage of an enemy. The authors recognize five sets of such fibres and they find that for each there is an appropriate type and level of ending in the midbrain roof.

This seems to be "form vision" at such a simple level that it is hard to believe that anything similar is responsible for our recognition of more complicated shapes. Nevertheless, there is some evidence that form vision in octopuses and perhaps in mammals depends upon the stimulation of certain cells that are analogues of the shapes that are recognized.

In octopuses it has been shown that the vertical and horizontal extents of figures are important clues by which their shapes are recognized. It is very interesting, therefore, to find that the retina itself and the optic lobe behind it are arranged on a vertical and horizontal plan (Plate IA). The eye is held approximately in one position wherever the head may be, by information derived from the gravity receptors of the statocysts. The retinal cells have their photosensitive pigment attached to a system of tubules so arranged that on each cell they lie approximately either in the vertical or horizontal plane. The cells are grouped in fours to produce the arrangement seen in Plate IB.

It is not yet clear whether this grid-like plan is connected with the recognition of the vertical and horizontal extent of figures. It may well be responsible for the capacity to detect the plane of polarized light, recently shown by Moody and Parriss to be possessed by octopuses.

The arrangement of the fibres of the optic lobes must almost certainly be connected with the coding system. Preparations by Cajal's method, in which all the larger dendrites and axons are stained, show that in the region where the optic nerve fibres end, the dendrites of the cells that they stimulate run mainly in the vertical and horizontal directions, less frequently obliquely (Plate IB).

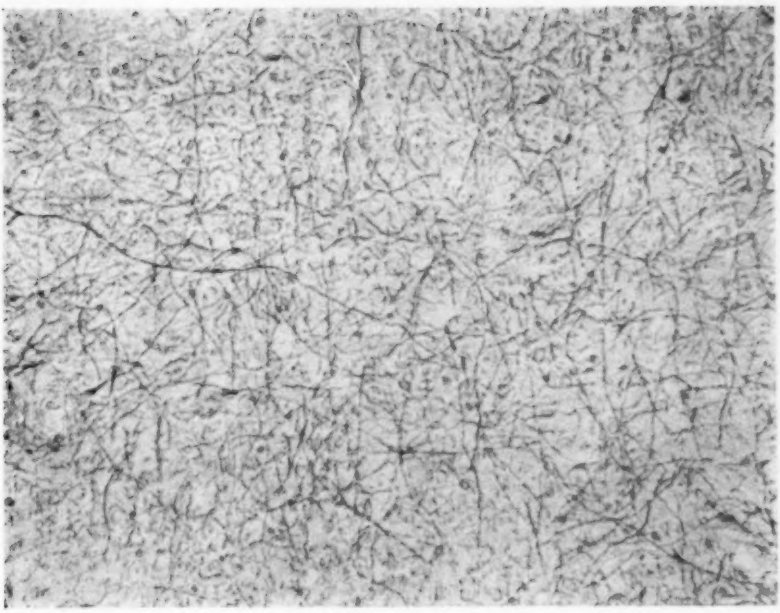
Such preparations show a nearly complete staining of all the main fibres and even of their finer twigs. They thus tell us the general directions of orientation, but the picture they give is too complicated and does not allow us to see the pattern of the branches of the individual cells. This is possible with the Golgi method, which picks out a small sample of cells and stains each of them completely. With this method we can also see the vertical and horizontal orientation and it seems that individual cells have oval receptive dendritic fields, with their main axis horizontal and the majority of the branches vertical (Plate IIA). Not all the cells are arranged exactly like this, however, and it will require much further study to work out the exact relations.

The suggestion is that each cell acts as a detector for a particular type of distribution of visual excitation. Some would respond to large areas extended in the horizontal direction, others to small vertical areas and so on. Exactly what a cell would respond to presumably depends on the distribution of synaptic endings over its dendritic system. Some of the branches carry twigs only at their ends and it might be that these would respond only to large figures. This would explain the fact that octopuses that have learnt to recognize large figures show only imperfect powers of recognizing smaller ones, although transfer from small to large is better. Incidentally, one of the striking facts is that these receptive dendritic trees spread so very widely among the endings of the optic nerve fibres. They may extend for a millimeter or more, that is to say over the area covered by even quite a large retinal image. But there are also many small ones and until we know more about their shapes and the distribution of their sizes we cannot say much in detail about how the coding system works. Other suggestions about it have been given, for example by Deutsch, and are discussed by Sutherland (1961). The plexiform zone, in which the optic nerve fibres end, contains an elaborate system of these receptive dendrites, organised into three main layers (Plate IIB). Among the endings there are also the twigs that represent the finest branches of millions of small cells, with fibres of very limited distribution. Both the layering and the small cells are also features of the retinas of vertebrates, including our own. The fact that similar arrangements occur in animals that have evolved independently for 500

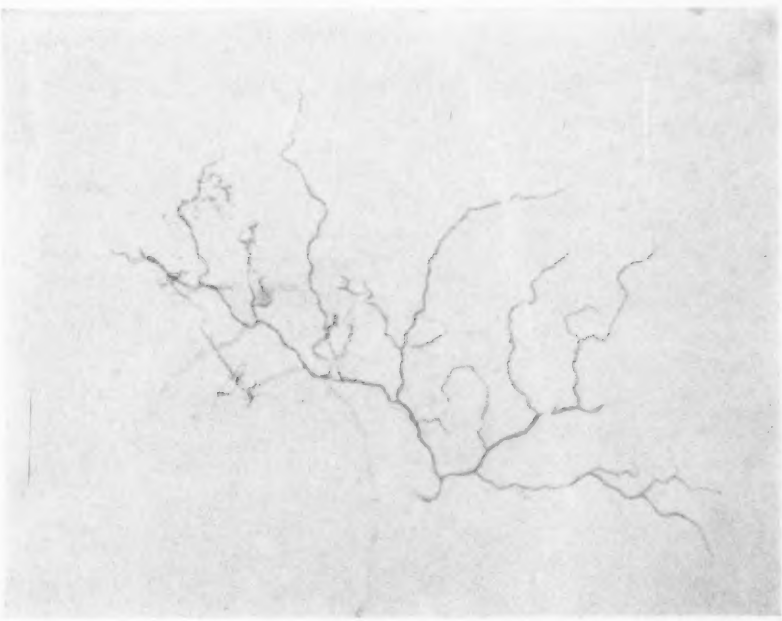
million years or more suggests strongly that they are of great significance for the recognition of shapes. Recent work by Hubel and Wiesel (1959) has shown that the retina and visual cortex of the cat also contain oval receptive areas. It is therefore not fantastic to suppose that even the high capacities for shape recognition by mammals employ a system of coding like that of the octopus.

In any case it is well worth while to pursue the matter further to find the details of the arrangement of these dendritic fields and of the course and distribution of their axons further on in the system. There may be cells at the centre of the optic lobe that are stimulated by certain ratios of excitation in the vertical and horizontal planes. The form of the dendritic trees may itself be important because of its isomorphism with some feature of the environment. The coding system then becomes not so much logical as an analogue, matching the input with a set of models in the brain, partly provided perhaps by heredity, partly built up by the experience of the animal, for example of a preponderance of vertical and horizontal outlines. Obviously we need to know far more of the control of the firing patterns of such dendritic trees, of the means of interaction between the results of input arriving at distant parts of them, and also how they came to have their particular shapes. Given a set of detectors for particular shapes of this sort we must then suppose that all are capable of eliciting a range of motor behaviour, but that any that are excited at the same time as some particular reward or punishment occurs become "switched" or "conditioned" so as to produce only the appropriate act thereafter. This selection and typing may be the function of others parts of the learning system, such as the vertical lobes of octopuses or the limbic system of vertebrates, which have circulatory connections with the optic lobe and cerebral cortex in which the neurons that are actually "switched" occur.

This may be speculative but in this field we must take what hints we can get. Such circulatory connections do occur and both in octopuses and humans the effect of removing the parts concerned is to make it impossible to "print" new representations of external events. Although we cannot say that we properly understand how shapes are recognised, we have some valuable



A. Section cut similarly to Plate Ib but stained with Golgi's method to show all the dendrites of a single large cell. The main axis runs horizontally.



B. Transverse section of the optic lobe of an octopus stained with Cajal's silver method. The plexiform zone lies to the left, the optic tract to the right.

PLATE II

clues from comparing octopuses and mammals. There is some isomorphism between the arrangement of their cells and the shapes that they recognize. A further clue is to be found in the layering of the nerve flexuses that pick up signals from the receptor units of the eye. There are many cells with short processes that end in these layers. Finally, further on in the system there are elaborate self-re-excitatory circuits, whose removal interferes with memory recording. Incidentally, these reverberatory effects also include efferent pathways by which the centres extend their influence outwards even to the receptors. The latter are thus by no means passive detectors—the centres may be dictating to them all the time what they shall see.

The thesis is then that the eye and brain form an adjustable analogue computer. By heredity and learning they acquire certain anatomical configurations dispersed among millions of cells. Each species of animal thus comes to be provided with cells that detect features of the light pattern that are relevant for its life. In our own case, among other responses, we utter appropriate words when light gets brighter and darker, when certain wavelength combinations occur and when there are certain patterns before our eyes.

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EXHIBITS IN THE LIBRARY

(*a*) A selection of electron micrographs of the eye, lent by *Professor J. Z. Young*.

(*b*) A display of colours illustrating colour contrast, juxtaposition, after-image, hue, tone and intensity, arranged by *The British Colour Council*.

(*c*) A Huxley microtome, lent by the *Cambridge Instrument Co., Ltd.*

EXPERIMENTS WITH DIVING SEALS

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Weekly Evening Meeting, Friday 11th November, 1960

L. B. W. Jolley, M.A., M.I.E.E.
Vice-President, in the Chair

ALL mammals can withstand complete submersion in water for a little while; but some forms are able to remain submerged at considerable depths for remarkable periods of time. It will be obvious that there are few accurate observations on the maximum length of time for which any mammal can remain under water: it would mean diving the animal to extinction. The following is a list of record durations of dives that have been taken from Scholander (1940), Scheffer (1958) and Harrison and Tomlinson (1960):

Pigeon	1 min	Grey Seal	20 min
Hen	3 min	Ringed Seal	20 min
Duck	17 min	Common Seal	28 min
Penguin	7 min	Porpoise	12 min
Water Rat	2 min 17 secs	Blue Whale	50 min
Rabbit	3 min	Sperm Whale	75 min
Dog	4 min 25 secs	Bottlenosed Whale	120 min
Muskrat	12 min	Man- pearl and sponge divers	2 min 30 secs

The maximum depth reached by a diving animal is as difficult to determine as the duration of a dive. The literature is full of anecdotes of fouling of cables, hooks and nets by seals and whales at immense depths, but there is no evidence that the animals were not dying before they became entangled or whether they would have survived had they returned to the surface. The following are a few recorded deep dives (see references for duration):

Penguin	at least 12 metres	Experimental dives
Weddell Seal	92 metres	Diving below ice
Common Seal	92 metres	Experimental dives
Grey Seal	146 metres	Caught on hook

A. Photograph of a newborn Common Seal pup weighing 11 kg.

B. Photograph of 2½-year-old male Common Seal. This specimen was exhibited in the Library after the Discourse (*Photograph by Dr. A. Herxheimer*).

PLATE I

Harp Seal	273 metres	Caught on hook
Porpoise	20 metres	Line attached
Fin whale	355 metres	Line attached
Sperm whale	900 metres	Entangled in cable
Man	165 metres	Flexible suit with special breathing mixture

All evidence indicates that young seals and whales cannot equal the performance of adults. Scholander (1940) records that a 4-month-old Grey seal pup on its first swim in deep water dived to 22 metres for a total time of 1 minute. A 6-month-old Hooded Seal dived spontaneously to 75 metres and remained submerged for over 4 minutes. A young Hooded Seal, which had been submerged the previous day for 18 minutes, was weighted by Scholander and submerged to a depth of over 300 metres in 3 minutes. It was drawn to the surface immediately after reaching that depth over a period of 9 minutes. The seal was reflexless on return to the surface, its heart beat very weakly, one pupil was widely dilated, one a short slit, the nostrils were firmly closed and it died shortly afterwards. No water was found in the lungs, but there was an abundance of air bubbles in the mesenteric arteries. Death was presumed to be due to air embolism.

Our experiments were carried out on pups, yearlings and adolescent Common Seals (*Phoca vitulina*) obtained from the Wash (Plate IA and B), East Anglia through the kind co-operation of the Eastern Sea Fisheries Joint Committee and the Hydrographic Survey Ship, H.M.S. Scott, (Commander H. R. Hatfield, R.N. then in command). Diving performance was assessed by immersion in a shallow tank, at sea, and under water or in air in a pressure chamber capable of simulating a pressure of 300 feet of water. Seals were secured to a board (Plate IIA) in a fashion similar to that described by Scholander (1940), or in a specially designed lace-up Terylene harness to enable free-swimming to take place at the end of ropes (Plate II B). Leads were connected from axillary electrodes to a portable Elmquist electrocardiogram. When required animals were anaesthetized with 3-10 ml. of a solution of 1 g. in 40 ml. sodium thiopentone injected into the extradural vertebral vein as if performing a lumbar puncture. Anaesthesia was subsequently maintained by introducing a

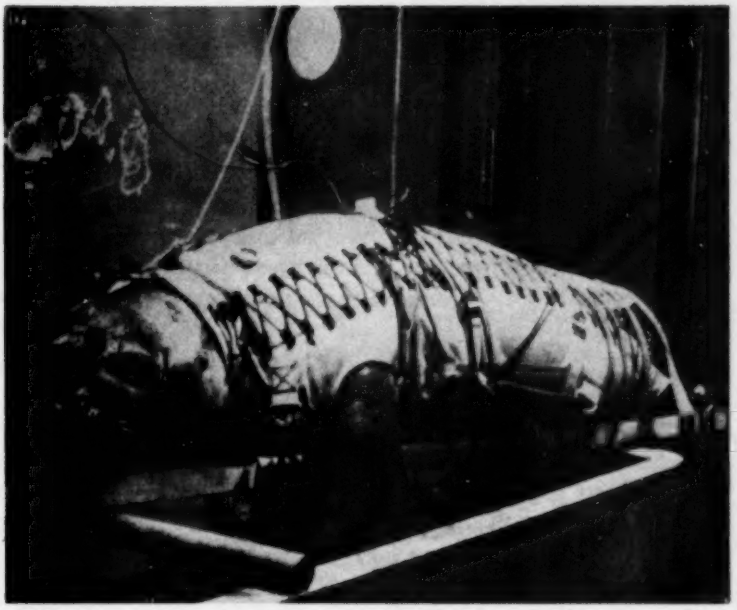
Magill's endotracheal tube (child's size) and administering nitrous oxide and oxygen.

Investigations of heart and respiratory rate were made on pups and young seals out of water and the heart rate was recorded during all experimental dives. The animals were secured as loosely as possible to a board or harness and were not anaesthetized during the dives unless specifically stated. No animal was dived again unless the heart rate and behaviour had returned to conditions prevailing at the beginning of the first dive.

Heart rate surfaced

This displays considerable variation, and even irregularity, in all animals whatever their age and whether or not they have recently dived. Young pups have a resting heart rate of from 90-180 beats per min; in 2-3 year-old adolescents it varies from 75-180 beats per min. Proximity to the investigator or indication to the seal that it is about to dive, (by submerging it a number of times for a few seconds) does not unduly influence the heart rate. Any tachycardia that resulted from a struggle to secure the seal to a board, or in its harness, soon subsided and seals often went peacefully to sleep during a pause in a diving programme.

Respiratory rate out of water is comparatively regular at 18-20 per minute in both pups and adults. It is less regular when the seal is immersed in a harness with only its nostrils above water. The heart rate increased from 112 to 144 when a seal was immersed suddenly to its neck, head still above water, and fell to 120 after 5 mins. It occasionally slowed from 120 to 60 for a few seconds following a respiratory pause longer than normal. This slowing of the heart associated with changes in respiratory rate has been described also by Irving, Solandt, Solandt and Fisher (1935) and Irving (1939). Forcible closure of the nostrils and mouth of a seal out of water (so as to prevent respiration) caused a fall in heart rate from 130 to 80 after 5 secs., to 48 after 22 secs., to 15 after 68 secs, and was followed by violent struggling that prevented further recordings. One yearling common seal was anaesthetized (with thiopentone, intubated, and then nitrous oxide and oxygen mixture used to continue the anaesthesia) and an attempt was made to determine the effect variations in respiratory rate would have on heart rate. Increasing the respiratory



A. Photograph of a 4-year-old Common Seal secured in a Terylene and nylon corset, with axillary electrodes for electrocardiographic recordings in position; experimental diving is due to commence.

B. Photograph of a 2-year-old Common Seal towing a Frogman.

PLATE II

rate artificially to 40 for a period of 2 mins, had no appreciable effect on the heart rate. The respiratory rate was then lowered to 5; after 1¼ mins, when the heart rate had dropped to 17, the animal collapsed, but was later resuscitated.

Tweaking the vibrissae caused episodic slowing of the heart rate to 75 beats per min. for a few seconds; smacking the face raised the rate to 165 beats per min. Throwing cold water over the face had little effect on the heart rate.

Shallow dives

Animals were dived, secured on a board, for periods of up to 28 mins. In a dive of this length intermittent struggling started at 15 mins. and became extreme during the last minute so the animals were brought to the surface. The diving bradycardia did not develop as rapidly as in *Halichoerus* (see Scholander, 1940); the slowest heart rate (6 beats per min.) occurred between 1 and 3 mins. after diving. Thereafter the heart rate gradually increased as time passed (Plate IV A). The degree of bradycardia and the rate at which it developed were not significantly affected by the rate at which the heart was beating before the dive commenced. Repeated diving of the same animal (after a short recovery period of a few minutes) did not influence the rate of onset, degree of bradycardia or recovery behaviour. There was always a recovery tachycardia lasting for 5-10 minutes after a dive of more than a few minutes. The slowest and longest lasting bradycardia was observed in older seals: the bradycardia also developed more rapidly.

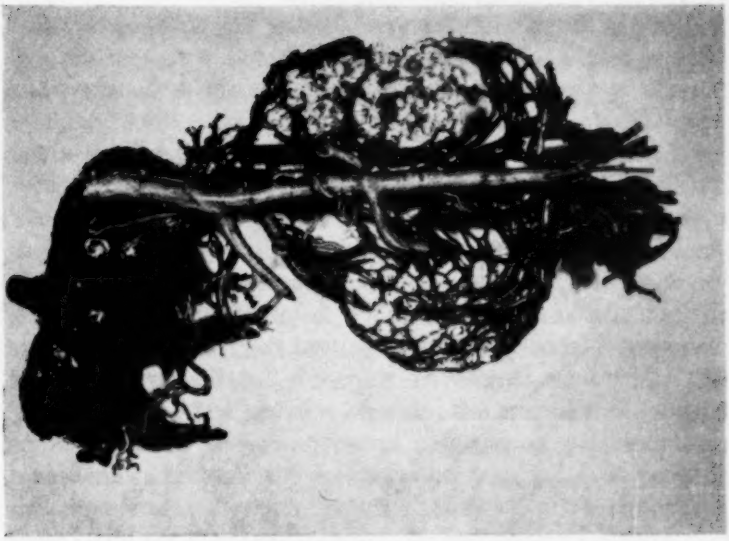
A two-year-old seal was secured in a harness that left its head, four flippers and tail free; guide ropes and electrocardiograph leads were attached. The animal swam freely in a shallow tank and dived for periods of several minutes. The heart rate showed changes similar to those recorded when the seal was secured to a board. It was noticed that the seal exhaled when it broke the surface after a dive; this observation has been frequently confirmed by us and is also mentioned by Matthews (1952). Another young seal behaved similarly in a harness when allowed to swim in the sea. It towed a small dinghy containing two men with ease at about walking speed and subsequently towed a skin-diver for a short distance under water.

A seal secured to a board was prepared for diving in a shallow tank; before diving and throughout the dive it was forcibly prevented from opening its nostrils or mouth. The heart rate was 144 beats per minute on the surface (nose and mouth closed) and fell to 24 beats per minute after 30 secs. It remained at that rate for 75 seconds after which it struggled so violently to exhale that no further recording was possible.

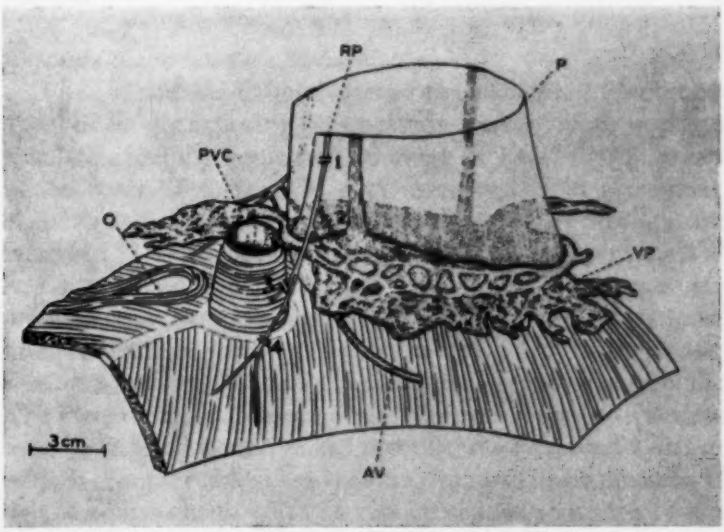
Deep dives

Three types of experimental diving were carried out; (a) pups a week old were lowered into the sea on a board; (b) two-year-old seals were placed in a tank filled with water inside a pressure chamber and the air pressure increased by stages to depths equivalent to up to 80 feet; (c) 2-year-old seals similarly secured were taken rapidly to 300 feet and kept there for periods up to 5 minutes.

The pups showed an immediate bradycardia to between 10 and 16 beats per min., but within a few minutes under water the rate began to rise to 30 beats per min. The older animals displayed an immediate bradycardia to 4 to 15 beats per min. which was maintained for 2.0 to 3.0 min. at depths in the pressure chamber equivalent to up to 200 feet. There was no indication in the older animals of a gradual decrease in the bradycardia as the dive progressed at a constant depth. There was, however, an increase in heart rate as the animal returned to shallower depths. The pups often showed a marked decrease in bradycardia after quite a short period (1-3 mins.) at only 20 feet. There was no noticeable change in the bradycardia of adolescent seals in dives of short duration up to 200 feet. One young seal, taken to about 100 feet, managed to raise its nostrils above the water in the pressure tank on return when at 50 feet. It appeared healthy immediately after the dive, and carried out shallow diving during the ensuing weeks without ill effect. Three months later the seal became anorexic, lost weight and was sacrificed. Extensive surgical emphysema was seen in the lungs, thoracic wall and vertebral venous system at post-mortem examination. It was concluded that the animal had inhaled air under pressure and ruptured a lung during the return to the surface.



A. Photograph of a Marco Resin cast of the abdominal blood vessels of a Common Seal pup seen from the back. The aorta, duplicated posterior vena cava and the hepatic sinus are well seen.



B. Diagram to show the position of the caval spincter above the posterior vena cava (PVC) and its nerve supply from the right phrenic nerve (RP), the pericardial venous plexus (VP) is also indicated. (*Reproduced by permission of the Zoological Society of London*).

PLATE III

A two-year-old seal was taken rapidly to a depth of 300 feet in 4 mins. 30 secs. It remained at this depth for 1 min. 20 secs. and returned to the surface by stages, pausing for 30 secs. at every 50 feet to make E.C.G. recordings (Plate IV B). On return to the surface the respiratory rate was 30 per min; the animal appeared fit and active, and displayed no signs of "bends". The same animal was dived to 300 feet the next day and kept there for 5 mins. Towards the end of this period the cardiac complex on the electrocardiographic recordings indicated some degree of physiological "defeat". The animal was returned to the surface and its heart was beating slowly on removal from water. Its pupils were dilated, muscular movements were weak. The heart stopped a few seconds later and the animal could not be resuscitated. At post-mortem no evidence of air embolism, lung damage or haemorrhage could be detected. It is possible that the animal suffered a "squeeze" at this depth such that the heart could not contract fully and cerebral anoxia followed.

Every seal was observed to exhale air when or just after it was immersed in water, and again later as the pressure increased in the chamber.

Exposure to increased air pressure

It was considered to be of interest to investigate the effect on a seal of simply exposing it to a steady increase of air pressure simulating depths equivalent to those it had "dived" when under water. Two-year-old seals were placed in a pressure chamber and allowed to breathe naturally as the air pressure was increased. The respiratory rate was assessed by counting the nostril openings over periods of half a minute. Increased air pressure equivalent to a depth below water of 200 feet caused a bradycardia from 120 to 30. It was not sustained, however, and the heart rate rose to 150 for periods lasting up to five seconds. The increase in air pressure caused the respiratory rate to slow from 24 to 8 and it was noticed that this was correlated with the periods of most marked bradycardia. Increase in air pressure to depths equivalent to 30 to 80 feet caused little slowing of the heart rate and no disturbance of respiration. The seals were in no way embarrassed by exposure to increased air pressure but did seem puzzled at the strange sensation. It appeared that only

when the seal held its breath was there any heart slowing, again indicating that the bradycardia is linked with interruption of regular respiration.

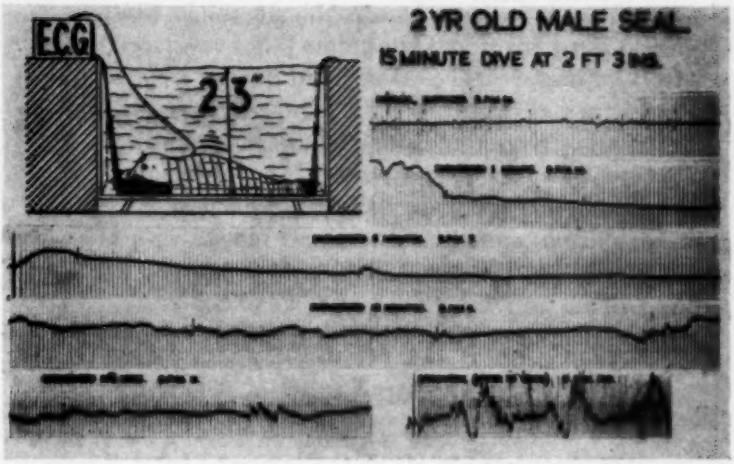
Stimulation and section of the phrenic nerves

A thick striated muscle sphincter is present on the posterior vena cava immediately cranial to the diaphragm in all seals we have examined (Plate IIIB). It is supplied by branches of the right phrenic nerve (Harrison and Tomlinson, 1956). To ascertain the effect of closure of the sphincter the posterior vena cava was clamped just caudal to the liver in an anaesthetized pup: this procedure had no effect on the heart rate in a surfaced animal. The right phrenic nerve was cut in the neck under anaesthesia in several young seals and they were subsequently allowed to recover. The animals were dived a few days later. In all there was an eventual bradycardia similar to that in normal animals, but the *onset* of the bradycardia was delayed. Stimulation for short periods of one or both phrenic nerves had no effect on the heart rate in surfaced anaesthetized animals.

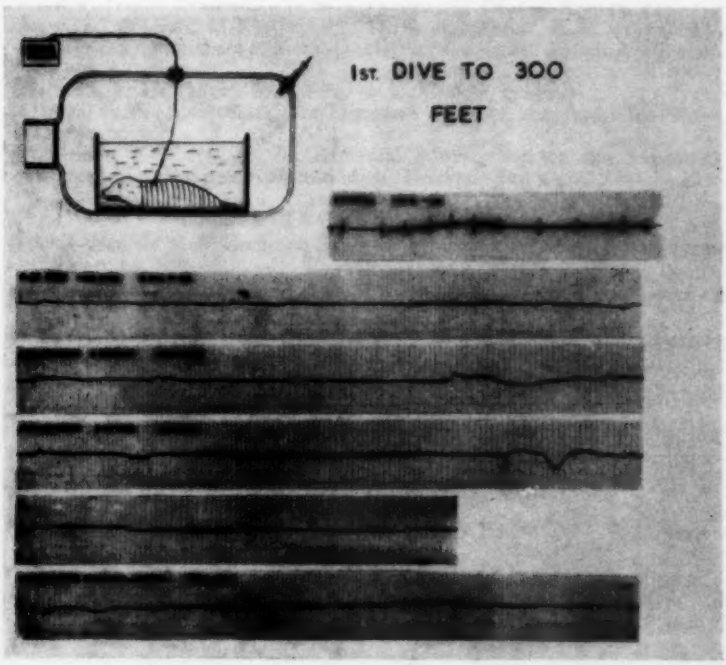
Stimulation and section of the vagal nerve.

Stimulation of the intact right vagus of anaesthetized pups resulted in slowing of the heart rate from 120 to 22, with immediate recovery to 120 on cessation of stimulation. Stimulation of the intact left vagus resulted in disappearance of the ventricular complex on the recording: P. waves continued to occur at 120 a minute. Stimulation of either vagus in an anaesthetized adult seal completely abolished the heart beat for the period it was applied.

Section of the right vagus in the neck in anaesthetized pups caused no change in the heart rate surfaced (180) and a fall to only 100 on diving. The beats were irregular. Section of both vagi in pups caused no change in the heart rate surfaced: in an adult the rate increased from 60 to 90. In short dives other pups with bilateral vagal section showed no slowing of the heart. Another was anaesthetized and both vagi were exposed: it was then dived and after the heart rate had fallen to 24, both vagi were sectioned with the seal under water. There was an immediate rise in heart rate to 156 which persisted for the remainder of the dive and after surfacing.



A. E.C.G. recordings of a 2-year-old Common Seal during an experimental dive in a shallow tank for 15 minutes.



B. E.C.G. recordings made during an experimental dive by a Common Seal under water in a pressure tank to 300 feet.

PLATE IV

Discussion of the significance of some of these findings is given by Harrison and Tomlinson (1960); the parts played by various vascular modifications in seals is discussed by Harrison and Tomlinson (1956) and Barnett *et al* (1958). Further observations and discussion will be published shortly.

During the discourse a tape recording was played of the heart sounds of a 2-year-old Common Seal before, during and after a 4 minute dive in a shallow tank. It recorded the slowing of the heart rate from 100 to 12 beats a minute during the dive with a recovery tachycardia of 120 on return to the surface.

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EXHIBITS IN THE LIBRARY

1. A 2½-year-old male Common Seal was exhibited wearing a diving corset and harness.
2. Various dissected parts and casts of the vascular system of seals were on display.
3. Recordings of numerous normal and experimental dives under varying conditions were laid out on cards.

Arranged by *Professor R. J. Harrison* and *Dr. J. D. W. Tomlinson.*

THE PERCEPTION OF SPEECH

By D. E. BROADBENT, M.A.
Director, Applied Psychology Research Unit of the Medical Research Council, Cambridge

Weekly Evening Meeting, Friday 18th November, 1960

Professor L. A. Jordan, C.B.E., D.Sc., F.R.I.C.
Vice-President, in the Chair

SPEECH is a topic which lies on the frontiers between a number of sciences: physics, physiology, phonetics, psychology. As far as applied psychologists are concerned, speech sets them a problem because it is used by human beings at work. Air traffic control, police information rooms, the telephone switchboards of large businesses, and many other places show the way in which the modern world expects men to deal rapidly and efficiently with a rapid barrage of spoken messages. If one starts from such practical situations, one very rapidly discovers a number of unsuspected features of the ear and the brain; and these in turn must be of importance in other practical situations.

In the first place, suppose one sets up a simulated situation resembling an air traffic control tower. The controller may be bombarded by messages from aircraft wanting to land, to take off, to get navigational assistance, or to appeal for emergency aid. In the laboratory all these messages can be laid down in advance, so that one knows whether or not the controller does the right thing about them. When this was done about ten years ago, it immediately became noticeable that the controller had a greater chance of making a mistake if two messages occurred at the same time. From one point of view this is obvious; because the sound of the first message might actually blot out the sound of the second. If this were all it would be trivial, but it is possible to show that some of the interference is due to other and more subtle factors. Suppose for instance that each message is stretched out, so that the words of one fall in the spaces between words of the other, thus:

The my cat aunt sat went on into the mat garden.

Such a mixture of two messages is very hard to understand, although the sounds forming each word are quite free of masking by other sounds. Similar difficulties appear even if the messages

are made up in an artificial language, to avoid the criticism that the habits we use in English have been disrupted; and it seems that the trouble is that the brain is hindered from selecting, as a separate group, those words which make up one message.

A number of experiments were of course immediately carried out to try and find ways of getting round this difficulty. It is a help if one voice speaks one message and a different voice the other: it is a help if a tone-control circuit is applied to one message so as to remove, say, all the sounds of low frequency from it and thus make it sound different to the other. But best of all is an arrangement in which one message comes from one direction in space, while the other message comes from a quite different direction. Two separate loudspeakers are much better than one coupled to both channels; and messages arriving over a stereophonic system are much more often correctly understood than they would be on a conventiohal system. Since our perception of the direction of sounds in space depends upon slight differences in the sounds at our two ears, the extreme form of this technique is reached by putting one message in one ear, and a quite different message in the other ear. This arrangement is an exceedingly good one for handling simultaneous messages; and has been put into effect in a number of places where the people who use it are probably quite unaware that their work has any contact with psychological research.

It is particularly striking that the separation of sounds into different places in space is of greater value when some of the sounds are irrelevant to the purposes of the listener. In the laboratory imitation of an air traffic control tower, there is a bigger difference between the numbers of correct answers to separated as opposed to combined loudspeakers, when some of the incoming messages are to be ignored. This means in fact that the difference in origin of the sounds is being used to discard some of them, and to select others for analysis and response by the brain. From some points of view it might be thought odd that the nervous system should in this way filter the information reaching the senses: at first sight it might appear that an efficient organism would respond to everything, instead of throwing away a good deal of available evidence about the world. The reason is presumably, however, that the brain has a limited size

and therefore a limited capacity for handling information, as man-made communication systems do. In the case of such mechanical systems, the limit on the number of messages which can be handled is set by the probability of each message, a low probability representing more "information" and therefore taking up the channel for a longer time if the code used is an efficient one. One might therefore suppose that the extent to which a human listener can handle two messages simultaneously does not depend upon the number of sounds reaching his ears, but rather upon the probability of each message. In fact, some experiments have shown that two very probable messages can both be understood by a man even if they arrive at the same time; but not two improbable messages. The control tower operator can sometimes understand the names of two aeroplanes which call him at the same time, because there are few names which might occur and thus the information per name is low. He cannot understand simultaneously two complicated messages, because there are a number of such messages which might have arrived, and so the information per message is high. Since therefore the listener has a limited capacity for processing information, it is not surprising that his brain selects only part of the data arriving at the senses, and that it likes to use means such as differences of place to identify the sounds to be accepted as distinct from those rejected.

The process of selection, and the means used by the listener to deal with momentary overloads of information, can be illustrated by an experiment of myself and Mrs. Gregory: a six-figure number is fired at a man with alternate figures being presented visually and auditorily. Under such conditions it is easiest to select one sense, say the eye, and concentrate upon that until the figures have all arrived. The other figures which reached the ear can then be remembered separately. So the man can best repeat the six-figure number with all the visual figures first and then all the auditory ones, or the reverse: he does not do so well at repeating the number in the actual order in which the figures arrived.

While it is easy to see in general terms that the brain is selecting all those sounds which have some property in common, it is more difficult to specify exactly what that property is, and especially so in the case where speech and noise come through

the same loudspeaker. A widely held view is that the ear contains a set of different sense-organs some of which respond to low notes and some to high notes: in fact, on this view the pitch of a sound depends upon the sense-organ which is stimulated. Now vowel sounds contain several different components at different frequencies: the vowel in "heed" contains for instance a good deal of energy at a rather low frequency, then little at medium frequencies, and another peak of energy at a somewhat high frequency. To identify a vowel correctly requires that the ear picks out the different components, and identifies them as belonging to the same voice and not to the background noise which in real life is probably present at all the intermediate frequencies. Although a particular vowel may excite certain quite widely separated sense-organs, and therefore certain fibres in the nerve from ear to brain, other fibres also will be active at the same time. What tells the brain that fibres A and D belong together and to the wanted voice, while fibres B and C do not?

To answer this question requires a preliminary examination of the physics of the voice. If we apply a pulse to some tuned object, say by tapping a glass with a knife, it will vibrate at its natural frequency and this vibration will then die away. A series of pulses will produce a vibration at the natural frequency but increasing in size with every pulse and decreasing between pulses. If this "amplitude modulation" is sufficiently marked, the resulting sound wave does *not* correspond in pitch to a steady wave having the natural frequency of the stimulated object. Many people would say that it had the same pitch as a steady wave whose frequency corresponds to the rate at which the pulses are being delivered. If for instance 256 pulses a second are applied to some object or electrical circuit tuned to 2560 cycles per second, the resulting sound has the pitch of Middle C (256) and not of the high frequency. But there is no doubt that this sound will do this even though it stimulates the sense-organs corresponding only to the higher frequency and not at all to the lower one. It seems therefore that the pitch of a sound depends, at least in part, not upon the sense-organ which is stimulated but upon some feature of the message travelling up the nerve fibre and affected by the rate of amplitude modulation of the sound. The most likely candidate is the number of impulses per second

travelling up the nerve. This number will increase when the sound is intense and decrease when it is weak: in the limiting case, there might be one impulse in the nerve for each of the original impulses applied to the tuned circuit, and thus the pitch of the sound would correspond to the frequency of impulses in the nerve.

Now in fact the process of generating speech in the head is not unlike the repeated tapping of a wine glass. Pulses of air pass up from the vocal chords and excite cavities in the throat and mouth: these cavities have their own natural frequencies, and so the resulting sound from each of them can be thought of as an amplitude modulated wave of the kind just discussed. There are several cavities, and therefore waves of different frequencies, but they are all excited by the same series of pulses and all the waves will increase and decrease in amplitude in time with each other. For each vowel, a talker will hold his mouth in a certain position and so produce cavities of certain sizes. When saying the vowel in "heed", he holds it in such a way that the largest cavity is pretty large and so resonates at a relatively low frequency, while the next largest is pretty small and so resonates at a relatively high frequency. For the vowel in "head", the two largest cavities are more nearly equal in size, and so resonate at two frequencies in the middle of the spectrum. In this way the characteristic spectrum of each vowel sound is obtained; and it is of course possible to carry out an analogous process simply by passing a series of electrical pulses simultaneously through several tuned circuits, and mixing the resulting waves. By varying the frequencies to which the circuits are tuned, one can get sounds which resemble different vowels, and by varying the pulse rate one can vary the apparent pitch or intonation of this artificial speech. With the aid of bursts of noise in the right places (to help with the consonants) complete meaningful sentences can be constructed in this purely mechanical way. The method was first demonstrated by Mr. Lawrence of Signals Research and Development Establishment, with his machine PAT. (It ought perhaps to be noted at this point that later forms of PAT connect the tuned circuits, corresponding to vocal cavities, in series rather than in parallel as the above account has described the process. The series connection gives a more direct analogy to

the actual process of articulation. The experiments to be mentioned were however carried out using parallel circuits).

It can be seen therefore that when energy is present at two widely separated frequencies in a vowel sound, each of those frequencies is being modulated (increasing and decreasing in size) at the same rate. And it was suggested earlier that when a sense-organ is stimulated by a modulated sound, the frequency of firing of the nerve fibre does in some way correspond to the modulation frequency. Is this then the clue which allows the brain, when receiving a number of different frequencies, to select those which belong to one voice? This theory can only be tested by using an artificial voice, because in a real one the modulation frequency has to be the same for all parts of the spectrum: but in the artificial case we can use a different series of pulses for the low frequency and for the high frequency tuned circuits, and so make sure that the resulting waves are modulated at different rates. This was done in a collaborative experiment between Mr. Ladefoged of the Edinburgh Phonetics Department and myself, and it appeared that the resulting speech sounded like several separate and unfused sounds.

A particularly striking finding was that if one inserts a low frequency wave into one ear, and a high frequency wave into the other, the listener will hear one combined sound in the middle of his head provided that both the waves are suitably modulated at the same rate. But if they are modulated at different rates, the listener hears one sound on each ear; and this is even so if the two waves being modulated are of the same frequency. The fusion of sounds reaching the two ears has also been studied in much greater detail by Professor Cherry and his students at Imperial College; and it seems that the important factor is that the sounds at the two ears be correlated. If the correlation is high a single sound will be heard; if low, two separate sounds.

It seems likely therefore that the selective mechanism within the brain can detect that certain of the incoming nerve fibres are firing in a similar pattern; and reject messages from other fibres which do not conform to this pattern. This principle, however, and the less sophisticated statements made earlier only concern the selection of particular inputs. The listener hears all the words, no matter what they are, which share some physical

property unrelated to their meaning. But in addition he is also more ready to hear some words no matter where they come from or who says them. A number of recent experiments at Oxford have studied this point. For instance, if a man is listening to words on one ear and repeating everything that he hears continuously, he usually knows little about any words that may have arrived at the other ear: he rejects them. But his own name is heard even if it arrives on the rejected ear. To take another case, suppose the message he is repeating is some series of meaningful words. Following such a series, some words are much more probable than others: for instance, following the words "The boy stood on the burning", it is most improbable that the next words will be "gaily mudguard singing upwards". If in fact one suddenly changes in this way from a systematic to a random series of words, while at the same time on the other ear changing from a random series to the systematic series "deck whence all but he had fled", the listener will continue to select the ear which his orders specified. But at the instant of the change he is liable to say "deck" even though that word reached the wrong ear. In yet another experiment a simple three-word phrase like "Mice eat cheese" was presented with the first word on the right ear, the second on the left, and the third on the right again. A three-figure number was also presented, each figure being simultaneous with one of the words but in the opposite ear. In this case, unlike the rather similar Cambridge experiment mentioned earlier, the listeners could reproduce all the words in the correct order and then all the figures or vice versa; and did no worse than if they selected all the information from one ear first and then that from the other. The orginal form of this experiment was open to the objection that hearing one or two words of the phrase might allow the listener to guess the rest; but an unpublished experiment by myself and Mrs. Gregory has eliminated this possibility. In our case we used a restricted set of phrases, telling the listeners in advance what the alternatives were, and arranged matters so that each of the possible first words could be followed by each of the possible second words, and so on.

So it seems to be possible to listen for words as opposed to numbers, just as one can listen to one ear as opposed to the other. But there is this important distinction between the two kinds of

selection, that the features of a given sound which identify it as a word or a number are to a great extent those which identify the particular word or number it is. The ear on which a word arrives is not a feature that identifies which particular word it is. So there is a logical distinction between the two kinds of selection, which makes it possible that they reflect different mechanisms in the brain. One might think on the one hand of the selection of a set of nerve fibres, and on the other hand of the selection of a set of possible responses to the message along these fibres. As yet however there is little experimental evidence to support this division into two mechanisms.

One last example should perhaps be given of the sort of evidence which may in the future distinguish between sensory and response processes. An artificial sound which people identify as the word "bit" may differ from a sound identified as "bet", by having a lower frequency for its first resonance. However, it is possible to make listeners judge exactly the same sound as "bit" on one occasion and "bet" on another, by preceding each of the test sounds by a special introductory sentence. The words of the sentence are identical, but in one case the first resonance is rather high throughout, while in the other case it is low. This sort of difference appears naturally in people with different sized heads, and apparently the listener can adjust himself to compensate for it. So the same test sound is heard as a different word, depending on the person who is thought to have said it.

But this is not a purely sensory adjustment: it is not a matter of the ear adapting to the range of frequencies presented, without reference to their meaning. The experiment only works if we use the same words but alter the sounds corresponding to the words. If we precede a vowel by words that all have a high first resonance, but do not make the frequency high *for those words*, there is no effect on judgments of the vowel. So this is a case in which one must consider, not simply the stimuli presented, but also the responses which have been given to them; and the two factors work in different ways.

All these results have practical implications; but in addition they have a bearing upon our view of human nature. The selective action of the brain, in picking out part only of its surroundings, is of importance when we consider the process of learning

by which people develop their full-blown adult behaviour. And the adjustment of response, to fit the particular voice that is being heard, is suggestively parallel to the adjustments that allow us to see objects as constant in size at varying distances, and so on. The advantage of studying these general problems in a particular practical application is, however, that one is forced to keep ideas concrete and to test them constantly by experiment. For this reason many applied psychologists regard their own branch of the subject as the place from which will come the ultimate theoretical understanding of human nature.

EXHIBITS IN THE LIBRARY

(*a*) An interference-reducing radio system based on the binaural fusion phenomenon, arranged by *Professor Colin Cherry and the Department of Electrical Engineering, Imperial College of Science and Technology*.

(*b*) Demonstration of the analysis and synthesis of speech and delayed auditory feed-back equipment, arranged by *Professor D. B. Fry and the Department of Phonetics, University College, London*.

RADIO ASTRONOMY AND COSMOLOGY

By MARTIN RYLE, M.A., F.R.S.
Professor of Radio Astronomy in the University of Cambridge

Weekly Evening Meeting, Friday 24th February, 1961

L. B. W. Jolley, M.A., M.I.E.E.
Vice-President, in the Chair

ASTRONOMY differs from most sciences in that we cannot do experiments; the astronomer must build up from his existing observations a picture or "model" of the Universe, and then look for further effects which should be observable if his model were correct. Although in 700 B.C. the Babylonians were making excellent observations without attempting to interpret them, and although the Greeks proposed models without always looking too carefully into how well they fitted the facts, this approach has always been present and in the 17th century led, through Kepler and Newton, to a good understanding of the solar system.

But what were the stars? Kepler had no conception of their great distance, and imagined them to be on the surface of a fixed sphere with a radius some 2000 times that of the earth's orbit. But it seems certain that Newton had, when he wrote:—

> "But if the matter were evenly disposed throughout an infinite space, some of it would convene into one mass, and some into another, so as to make an infinite number of great masses scattered great distances from one another throughout all that infinite space. And thus might the Sun and fixed stars be formed, supposing the matter were of a lucid nature."

We can see here the first idea of an *infinite* Universe, in which the Sun has no more significance than any of the stars.

There now began the exploration of space on an ever-increasing scale. William Herschel, by constructing larger telescopes than had ever been built before, was able to show that the diffuse band of light of the Milky Way, was in fact due to countless stars, and he thus confirmed Newton's suggestion of the insignificance of the sun. Today we know that our own Galaxy, the Milky Way system, is a flattened disc containing some 100,000 million stars each comparable in size and luminosity with the Sun.

But the observations of William Herschel and later his son

John showed, besides the millions of star images, some thousands of diffuse sources of light or "nebulae". Some of these are now known to be clouds of luminous gas in our Milky Way system, but even at that time the Herschels considered the possibility that these sources were themselves distant "island Universes" too far away for any of the stars to be resolved individually. It was not until methods of distance measurement had been established in the present century that these suggestions could be confirmed, showing an apparently limitless Universe containing at great separations, compact islands of stars, or galaxies, of which the Milky Way is one.

Besides showing the insignificance of the earth, these observations raised new problems. One of these, first propounded by the German astronomer Olbers, is based on an observation which any of us can make—that it gets dark at night.

If we look at the sky we see that between the stars it is dark; a larger telescope will see fainter stars here, but again it is dark between them. Now if we must suppose that the Universe is infinite in extent, then in whatever direction we look we will eventually see the surface of a star. Although the intensity from each star individually will be very weak, since they must occur in every direction, the sky should have the same brightness as the surface of the sun: but if this were the case the earth would be heated to 6000° and would immediately be vaporized.

We cannot avoid the difficulty by supposing that the light from distant stars is absorbed; by the very fact of absorbing the light the obscuring matter will be heated until it has the same temperature as the stars—when it will radiate as much light as it absorbs.

It seems that we can only explain this paradox by supposing that the Universe is not infinite—but if we ignore the local stars in our own Milky Way system, we find that the sky is uniformly dark in all directions, and we should have to return to a pre-Copernican idea of a Universe constructed with us at its centre, having in the meantime demonstrated our complete insignificance.

The discovery which eventually led to the solution of the problem was made by the American astronomer Slipher, in 1912. Slipher, who was studying the spectra of the stars in distant

galaxies found that for a particular galaxy, the spectral lines were displaced slightly, and all occurred on a slightly longer wavelength than expected. This displacement of the lines towards the red end of the spectrum, the so-called "red shift", is just what would be expected if the light were emitted from a moving source, just as the pitch of a passing train whistle appears to decrease after it has passed us. His observations suggested that not only this galaxy but also a number of others were all moving away from us, and later work led in 1928, to the conclusion that no matter in what direction one looked, the galaxies were travelling away from us; it was also found that the speed of recession was greatest for the most distant galaxies.

We can now see an explanation for the darkness of the night sky; the light we receive from a very distant galaxy will have suffered such a large red-shift, that most of its energy now falls in the infra-red; any visible light received must be emitted in the ultra-violet, where the energy emitted is very small. As a result the light from galaxies beyond a certain distance will be very small, and we have in effect produced a limit to the size of the Universe we can see.

Although we have found an explanation for the observations, we have had to introduce the idea of a Universe changing with time, and if we relate the rates of recession of galaxies at different distances, we must conclude that all those which we now see must have been crowded close together about 10,000 million years ago. This "age of the Universe" is little more than twice the age of the earth as indicated by the radioactivity in the oldest rocks. Although the observations cannot indicate whether this period of high density should be regarded as the "Creation" or simply a phase in a Universe whose density varies periodically, they do imply that the appearance of the surrounding Universe is changing with time.

In 1948 however, Bondi, Gold and Hoyle proposed an entirely different model, based on the supposition that the Universe as a whole is completely unchanging with time. In order to account for the expansion of the Universe and the consequent loss to view of distant galaxies, they introduced the idea that new matter is continuously created everywhere throughout space; this matter will eventually condense to provide new galaxies to re-

place those lost to view through the expansion. Although many types of observation and experiment have suggested that matter and energy cannot be created or destroyed, it has never been verified with an accuracy sufficiently high to rule out the theory of "continuous creation".

If we accept this Steady-State theory we have a model which has the philosophical attraction that the Universe presents the same appearance no matter from where, or at what time it is observed. It is a Universe unlimited in space or time, and the only unfamiliar feature which we have to accept is that the law of conservation of matter and energy is not *quite* true.

What we must now ask is whether any of the models proposed bears any resemblance to the *actual* Universe? Here we need to look for subsidiary consequences of the different models and see whether any form the basis for observational test. Whilst it is likely to be very difficult to distinguish between forms of evolving cosmology, there is a good chance that there are detectable differences between *any* evolving model and the Steady-State model. In the evolving case we shall expect to find a progressive ageing of the galaxies, and the average distance between galaxies will steadily increase; on the Steady-State model new galaxies are being born to replace those lost by the expansion and we shall always find a mixture of old and young galaxies in any sample we choose.

If therefore we could compare a photograph of the surrounding galaxies taken a thousand million years ago with one taken today, we should be able to make this distinction. Although this particular experiment is impossible, we can do something very like it by observing galaxies at a distance of a thousand million light-years. What we see is a picture of these galaxies as they were when the light left them, and since the light has been travelling for a thousand million years, we can see what changes have occurred in this time by comparing them with nearby galaxies, from which the light has taken a much shorter time to reach us. By extending our observations to greater and greater distances we can in this way explore back to earlier and earlier periods in the history of the Universe. This is the reason why astronomers want to study the faintest galaxies, and why the great 200-inch telescope on Mount Palomar was built.

Unfortunately even with this telescope it has so far proved impossible to reach any definite conclusion, owing to the difficulties of making sufficiently accurate observations of sufficiently distant galaxies.

There seemed little hope of overcoming a barrier apparently so serious, but in 1952 a most remarkable discovery was made—that the second most intense source of radio waves which had been detected in the new science of radio astronomy, was a very distant galaxy, at a distance of 500 million light years; its intensity showed that its radio emission was about a million times more powerful than that of our own or other nearby galaxies.

The fact that a source of such power could exist was surprising enough, but almost as remarkable was the evident rarity of such sources; there are about 100 million galaxies within a distance of 500 million light years, and yet only this one produces radio emission so intense.

More detailed observations with the 200-inch telescope at Mount Palomar suggested that this source was a collision between two complete galaxies. This explained both the rarity of the sources (for the chance of such an encounter is extremely small) whilst the collision supplied the additional energy needed to maintain the powerful emission of radio waves.

The existence of such a source suggested at once the possibility of exploring to greater distances, and thus to earlier stages in the history of the Universe than would ever be possible in optical astronomy. But before we can use radio observations to test any particular cosmological theory, we must find some quantity which we can predict according to the theory, and which we can also measure. One such quantity, as we have seen, is the density of galaxies at different distances—or equally well, the density of radio galaxies. But in this case we have no way of measuring distance directly. If we knew the average power of the sources we could use their intensities as a measure of distance.

The first problem is therefore to find the power of the sources, so that we can predict according to a given cosmological theory, the relative number which we should expect to find in a given range of intensity. We can then compare these results with the actual numbers we find from our observations. We must endeavour to make this comparison for the weakest possible

sources—for the further we can penetrate in distance—or the further back in the history of the Universe we can reach, the greater will be the differences between the predictions of the different cosmological models.

It seemed impracticable to build an instrument of sufficient size by conventional means, but at Cambridge we have developed a new method of obtaining a very large resolving power, by moving a smaller aerial to different positions within a much larger effective aerial. Our new instrument consists of two elements, one of which is 1450-ft. × 65-ft. and aligned East-West; the other is a smaller aerial 190-ft. × 65-ft. mounted on railway

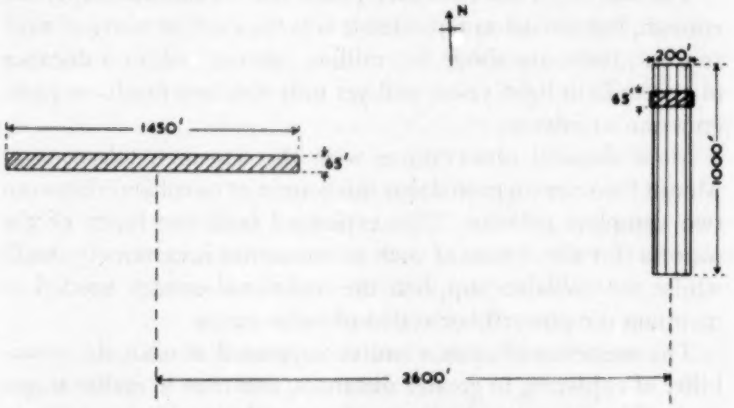


FIG. 1. Diagram of the Cambridge Interferometer.

lines 1000-ft. long running North-South (Fig. 1). The earth's rotation scans the beam round a 4° strip of sky each 24 hours, the strip being selected by the elevation of the two aerials.

In each set of observations, the moving aerial is driven to the North end of the rails and the observations are recorded (as holes in punched tape) for 24 hours; we then move the aerial by about its own width and another set of observations is made. After 25 days we have all the information we need to produce a map of the whole 4° strip.

In order to do this we must make about a quarter of a million calculations, and these are made on EDSAC, the computer of the Cambridge University Mathematical Laboratory. The output of the computer is printed on sheets which enable us to find

the positions and intensities of the sources, and the detail obtained is the same as if we had built two aerials each 800-ft. by 500-ft.

We have been using this telescope continuously since it was completed in the summer of 1958, most of the time on problems relating to the cosmological question.

Our first problem was to establish the power of the sources—so that we could predict the relative number of sources we should expect to find at different intensities. At the same time we must

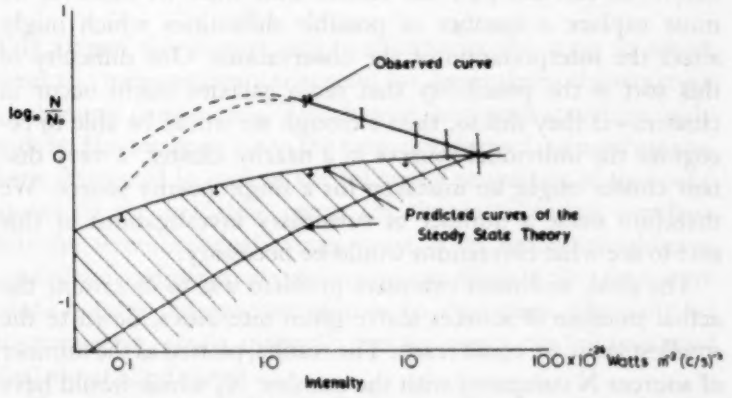


FIG. 2. Plot of relative number of sources observed (N/N_0) above given intensities I. The dotted lines represent the extension of the observations to weaker sources than can be observed individually; they are based on a statistical method which gives no information about the positions or intensities of individual sources, but allows limits to be set to the number of sources of different intensities.

The full lines are the curves predicted by the Steady-State model for two values for the effective power of the sources.

make sure that the observations are not being diluted by large numbers of relatively weak sources at small distances—for we know that some of the sources are the remains of supernova explosions inside our own Galaxy—while others are nearby galaxies with relatively weak radio emission.

We have used three methods of finding the power of the sources, the first of which is based on radio methods alone, and involves no assumptions about the nature of the sources. This method showed that only a few per cent of the observed sources were within the Galaxy, and that most of them were external

galaxies having a radio emission at least 1000 itmes greater than that of our own Galaxy. If we suppose that most of the sources emit as much *optical* radiation as our own Galaxy, then the limiting optical brightness of the sources allows us to set an even greater limit to the radio emission. The third method was based on measurements of the angular diameters of the sources, and again indicated an average radio emission 10^4—10^5 times that of the Galaxy. From these results we can now compute the number of sources we should expect to find at different intensities, but before we can compare the results with what we observe, we must explore a number of possible difficulties which might affect the interpretation of the observations. One difficulty of this sort is the possibility that radio galaxies might occur in clusters—if they did so, then although we would be able to recognize the individual sources in a nearby cluster, a very distant cluster might be mistaken for a single nearby source. We therefore made a number of subsidiary investigations of this sort to see what corrections would be necessary.

The final, and most extensive problem was to determine the actual number of sources above given intensities, down to the smallest value we could reach. The results, plotted as the number of sources N compared with the number N_0 which would have been observed in the absence of effects of the red-shift are shown in Fig. 2. The corresponding curves predicted by the Steady-State model on the basis of (a) the lowest permissible value of radio power and (b) the value suggested by the optical data are also shown in Fig. 2. The discrepancy seems too great to be explained by errors in the observations or their interpretation, and suggests that the Steady-State theory in its original form does not correspond to the actual Universe.

This is only the beginning of the problem, and the simplest of the questions which one can ask. There are many versions of evolving cosmologies, and there may be special cases of the Steady-State model which fit the present results. More detailed observations may make it possible to eliminate some of these too.

EXHIBITS IN THE LIBRARY

A display of models of the Cambridge radio telescopes, photographs, slides and diagrams illustrating principles and techniques of radioastronomy, arranged by *Professor Martin Ryle*.

MAGNETISM AND CHEMICAL ARCHITECTURE

By R. S. NYHOLM, D.Sc., F.R.I.C., F.R.S.
Professor of Chemistry, University College, London;
Professor of Natural Philosophy, Royal Institution

Weekly Evening Meeting, Friday 17th March, 1961

R. Holroyd, M.Sc., Ph.D., F.R.S.
Vice-President, in the Chair

(Summary of the discourse)

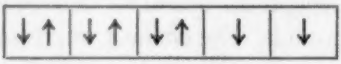
THE aim of this lecture was to summarise the ways in which magnetic measurements are useful for determining the structure of chemical compounds. The chemist interprets structure fairly widely. Having been given the empirical formula of a substance, he is interested in each of the following properties of the metal atom: (i) the oxidation state; (ii) the coordination number; (iii) the stereochemical arrangement of its nearest neighbours (and of the conformations which they can display); (iv) the nature of the bond to the attached ligands. In ideal cases, especially for the transition metals, magnetic measurements can tell us a good deal about all of these.

Chemical compounds usually have magnetic susceptibilities much smaller ($\times 10^{-3}$ or 10^{-6}) than those shown by the common ferromagnetic materials like iron. Some use has been made of diamagnetism for the elucidation of the structure of organic compounds but its use in inorganic chemistry—with which we are mainly concerned—is negligible except in so far as it indicates the absence of unpaired electrons.

Paramagnetism arises because unpaired electrons possess angular momentum of *spin* and, usually, of *orbital* motion as well. The way in which these combine to give rise to a resultant total orbital angular momentum depends upon a variety of factors. Especially important is the energy of the separation between atomic levels and the symmetry of the electrical field arising from the attached ligands. The magnetic moment due to l, the number of units of orbital angular momentum, is given by $\sqrt{l(l+1)}$ Bohr Magnetons, whilst that due to spin (s) is given by $\sqrt{4\,s(s+1)}$. For an atom with a small separation

between possible energy levels (J values), $\mu = \sqrt{4s(s+1) + l(l+1)}$ B.M., whilst when the separation is large, $\mu = g\sqrt{J(J+1)}$ where g is the Lande splitting factor and J is the vector sum of l and s.

Now for many atoms the value of l is negligible and from the value of μ we can deduce readily the value of s and hence the number of unpaired electrons. From the number of unpaired electrons we can deduce the oxidation state and, as a rule obtain some idea of the stereochemistry. Thus, the electron configuration of a free Ni^{++} ion is



with two spins; when this bivalent ion occurs in a compound such as $[Ni(H_2O)_6]C6_2$ or $[(C_2H_5)_4N]_2NiCl_4$ in which *no* electron pairing occurs one can conclude that the compound is either octahedral or tetrahedral in shape. If, however, electron pairing takes place as in, for example, $NiCl_2.2(C_2H_5)_3P$, or $[Ni(Diarsine)_3]Cl_2$, it is safe to conclude that the attached atoms have a square or a tetragonal arrangement about the metal atom.

We can go further in predicting the stereochemistry if we know the value of the orbital contribution. Thus, for a Nickel II compound containing two unpaired electrons a magnetic moment of 2.83 B.M. is expected provided the moment is due to spin only. If however orbital motion is possible a value as high as 4.1 B.M. can arise. It was on this basis that the compound $[(C_2H_5)_4N]_2\ NiCl_4$ with a μ of 4.0 B.M., was first suspected to be tetrahedral.

Finally, one can obtain useful information concerning the nature of the metal-ligand bond from magnetic measurements. For example an Ni^{2+} ion in a perfect octahedron with a strong electrical field and with no covalent binding should have a magnetic moment of 2.83 B.M. In practice, this value lies between 2.9 and 3.4 B.M., the increase being due partly to the "mixing-in" of excited states, which we can calculate and partly owing to the fact that the Ni atom does not really have two positive charges on it at all. This decrease in positive charge can be

correlated with the % covalent binding (electron sharing) between the metal and ligand.

This brief summary provides an outline only of certain uses of magnetism; for a more detailed discussion the reader is referred to the references listed below.

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6. Figgis, B. N. and Lewis, J. *Magnetochemistry of complex compounds*. Ch. 6 p.400-454 in *Modern coordination chemistry*, ed. by Lewis and Wilkins. London, Interscience. 1960. (This review contains an excellent survey of recent work).

EXHIBITS IN THE LIBRARY

(a) Magnetic susceptibility meter, lent by *Electronic Instruments, Ltd.*

(*b*) Tyndall's apparatus for investigating diamagnetic force, from the *R.I. Collections*.

(*c*) A selection of Tyndall's manuscripts relating to diamagnetism and some early books on alchemy, from the *R.I. Library*.

LIBRARY CIRCLE MEETING

Thursday, December 1, 1960

FORGOTTEN WORTHIES OF THE ROYAL INSTITUTION

(1) WILLIAM THOMAS BRANDE (1788-1866)

By EDWARD IRONMONGER, B.Sc., M.R.I.

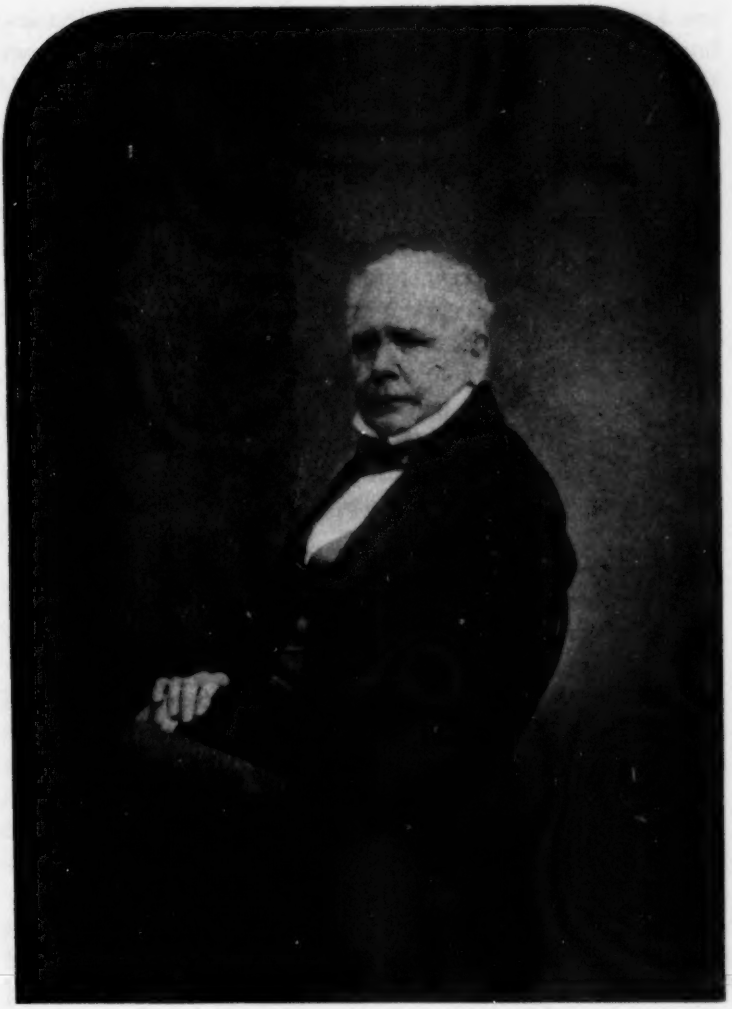
Brigadier H. E. Hopthrow, C.B.E., M.I.Mech.E., in the Chair

IN the story of the Royal Institution during the nineteenth century, the names of Davy, Faraday, Tyndall, and Dewar appear prominently and the fame which the Institution acquired was largely of their making. Nevertheless, in the background, there are several other figures who have become the forgotten worthies of this place. Among these is one, William Thomas Brande (Plate I), whose achievements here deserve to be better known. The following pages are in the nature of an interim report, with many loose ends and with much still to be discovered about one who served this Institution loyally for forty years.

He was born in 1788, the sixth and youngest child of a gentleman who came over from Hanover and was some-time medical attendant to George III. After four years at a private school in Kensington, he went to Westminster School but did not proceed further to the University. It was his father's wish that he should enter the Church but he was strongly inclined to medicine. His later attachment to chemistry and mineralogy was acquired from a Mr. Charles Hatchett whom he assisted in his laboratory at Chiswick and whose youngest daughter he married. In 1804 he became a pupil at the Anatomical School in Great Windmill Street and also studied chemistry at St. George's Hospital. Of this period, he writes,

> "I was now full of ardour in the prosecution of chemistry .... I found time, however, to read, and often to experiment in my bedroom late in the evenings. I thus collected a series of notes and observations which I fondly hoped might at some future period serve as the basis of a course of lectures, and this in time they actually did."

His first contribution to scientific literature was an article on Benzoin, published in *Nicholson's Journal* in 1805, when he



William Thomas Brande (1788-1866)

PLATE I

was only 17 years old. He was elected F.R.S. in 1809 and was awarded the Copley Medal for two papers "On the State and Quantity of Alcohol in Fermented Liquids" published in the *Phil. Trans.* 1811-1813.

Davy resigned his chair of Chemistry at the Royal Institution in 1812 and in May 1813, Brande was elected Professor of Chemistry and then, five months later, Superintendent of the House. In October 1813, young Michael Faraday offered to resign from his post here to accompany Davy on his travels. In spite of Brande's suggestion that suitable arrangements could be made to cover Faraday's absence, the Managers accepted the resignation and Faraday was paid a month's salary on his departure. Fortunately two years later, on the recommendation of Brande, Faraday was reappointed at 30*s*. a week. If for no other contribution to the Royal Institution, this forgotten worthy deserves our thanks for supporting the return of Michael Faraday.

Whilst retaining his Royal Institution appointment, Brande was appointed Superintendent of the Die Department at the Royal Mint in 1825; but later, in 1852, on his appointment as Superintendent of the Coining Department, he resigned his Professorship at the Institution. He also served for ten years as one of the Royal Society Secretaries, was one of the original Fellows of the University of London, served for twelve years as an Examiner in Chemistry for that body and was elected Honorary D.C.L. at Oxford in 1853. He died on February 11th 1866 and was buried at Norwood.

His work in science was extensive, if not spectacular. In 1812 he was asked to report on the laboratories belonging to the Society of Apothecaries and shortly afterwards he was appointed Professor there. From then until just before his death he seems to have been actively concerned in the affairs of the Society. He lectured there and made various suggestions for the improvement of courses. He was appointed successively Junior Warden (1849), Senior Warden (1850) and Master (1851). In 1858, the Society voted a sum of 100 guineas for his portrait, by Weigall, which was exhibited in the Royal Academy in 1859 and which was finally hung in the Hall of the Society. As has already been stated, Brande became a pupil in the Anatomical School in

Great Windmill Street in 1804 and he started lecturing there four years later. This school had been founded by Dr. William Hunter, who was later joined by his brother John. The museum of anatomical and pathological preparations attached to the School was unrivalled at that time and was later bequeathed to Dr. Wilson who finally sold the whole establishment to Sir Charles Bell. When Brande was appointed Superintendent of the House at the Royal Institution it was suggested by him that the chemistry lectures which he was giving at Great Windmill Street as well as lectures to medical students elsewhere should be transferred to Albemarle Street. This was done (see *Proc. Roy. Instn.* 1958, **37**, 144-8) and the lectures were apparently very successful. Among the pupils at these lectures was one who himself was to serve the Royal Institution in later years, H. Bence Jones (Plate II), who in his *Private Autobiographical Notes* writes

> "On October 1st 1838 I became a perpetual pupil at St. George's and began to attend lectures and the dissecting room. I then for the first time went to the Royal Institution, where Mr. Faraday, at eight in the morning, gave a short course of lectures on electricity, which preceded Mr. Brand's general chemical course for the medical students of St. George's. Those lectures of Mr. Faraday's, beautiful as they were, were of small use to medical pupils, who could not see much connection between electrical induction and the action of drugs."

Nevertheless Brande's lectures must have been very successful for when he wrote to the Managers of the Royal Institution in November 1846 asking to be allowed to resign from giving these lectures, they paid tribute to his powers as a teacher and to the work he had done in raising the prestige of the Institution. In fact, after concern had been expressed by the authorities of St. George's Hospital, Brande agreed to continue the morning lectures to medical students.

Brande was also concerned with the attempt to establish a School of Practical Chemistry. In October 1843 he raised the question with the Managers and the idea was favourably received, the President, Lord Prudhoe writing,

> "There is no doubt that a School of Practical Chemistry must soon be established in London, and considering the advan-

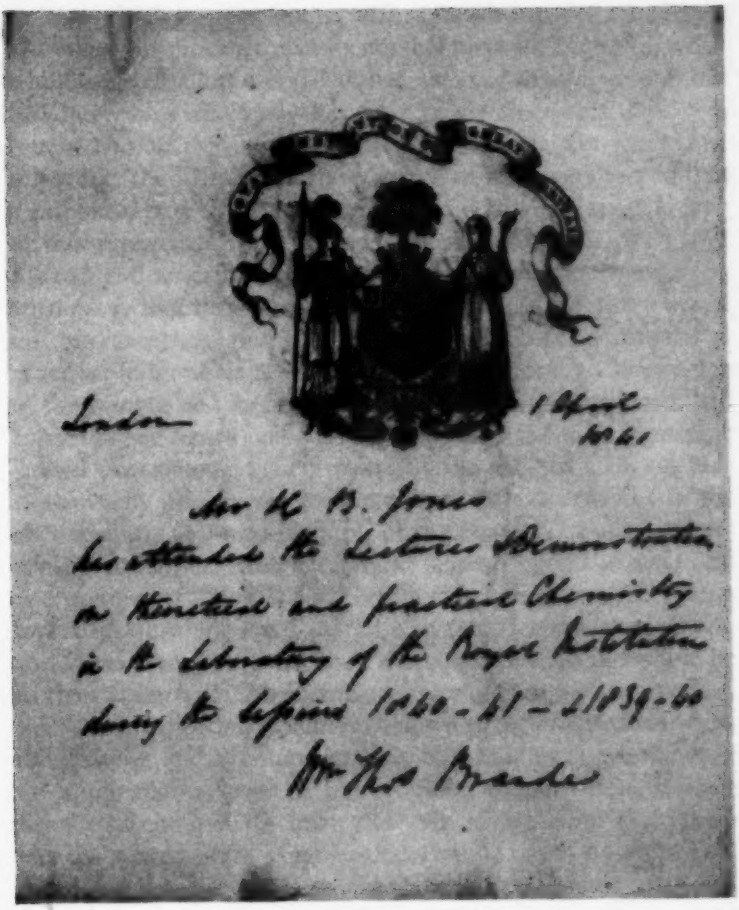

London
1 April
1861
Mr H. B. Jones
has attended the Lectures & Demonstrations
on Theoretical and practical Chemistry
in the Laboratory of the Royal Institution
during the Sessions 1860-61-1859-60
Wm Thos Brande

PLATE II

tages which it possesses, as well as its constitution, the Royal Institution appears the most suitable place for such a School."

Space will not allow a detailed discussion of this suggestion but one interesting discovery has been made since this topic was touched upon previously in these *Proceedings*. On December 9th, 1843, the Minutes of the Meeting of Managers record that a printed report by Brande and Faraday was presented. A copy of this report has recently been discovered by Mr. K. D. C. Vernon and we can judge the extent of the scheme from it. The writers say that the object of such a School of Chemistry would be "to create through the country a new class of chemists not so remarkable for their number, as for their thorough knowledge of the Science and its practice. The students, it is believed, will consist of gentlemen being lovers of the science for its own sake: landed proprietors, agriculturists or the sons of such, as also of the many others who are connected with or attached to the chemical arts and manufactures of the country." Such a school could not support itself but would depend upon the good will and opinion of "Noblemen, Gentlemen, and others who being lovers of knowledge and patriotic in their feelings, are willing and forward to give such a boon as a school of this kind would be to their country." The Provisional Committee had approached the Royal Institution as a body "known to the civilised world, as the Fosterer and Promoter of Science". It is recognised that, if the application is granted, the proposed School would displace Brande's School of Chemistry for Medical students and others but the writers were satisfied that Brande could be accommodated for these lectures in the Model Room. The proposed School was not to be part of the Institution in government and funds (unless the Managers so desired) but would compensate the Institution for the expenses incurred in the rearrangements. The responsible body for the proposed School would probably be a Committee on which some of the Officers of the Royal Institution would serve.

Finally the Report proposes the following resolution to the Managers:

"Considering the great object of the advancement of chemical Science, and of good to the community contemplated in the establishment of the proposed School, and the perfectly dis-

interested views and intentions of its promoters and supporters the Royal Institution is willing and anxious to aid such an object as far as it can consistently with the rights and priviliges of its members; and if hereafter the proposers of the School return to the Managers in possession of the names of supporters and of pecuniary means sufficient to carry out the object proposed, strictly on the principles laid down in this Report, the Managers will on their part be prepared to recommend to the Members of the Royal Institution, the appropriation of apartments in the house for the purpose of a scientific laboratory for the School."

It should be noted that these closing words reflect great credit on Brande and Faraday in recommending a proposal which would have seriously interfered with their convenience and comfort in the pursuit of their own work. However it was not to be. At their meeting on December 26th 1843, the Managers abruptly and unexpectedly rejected the whole idea which seemed to have commanded strong support from everyone concerned. It would be interesting to know what lay behind such a complete change of heart and perhaps further material will be found which will throw light on the whole affair.

Throughout the whole of his long period of service to the Royal Institution, Brande was actively engaged in lecturing on a variety of subjects, including such topics as chemistry, geology, electro-magnetic clocks, electricity, London's water-supply, the business of the Royal Mint, etc. In addition he gave seven courses of Juvenile Christmas Lectures. In his farewell speech to the members in 1852 he said :

"The teaching of chemistry *here* has always been a delight to me; and to have successfully taught it for so extended a period, and to such an audience, has been, and indeed can be, the privilege of a very few; and believe me, I duly appreciate it, and that I look back with feelings, which I cannot represent in words, at the confidence which the successive Managers of this Institution have placed in me; and at the uninterrupted kindness and attention with which my imperfect endeavours to set forth the truths of chemical science in their varied relations, as evidence of the wisdom, power, and beneficence of the Creator on the one hand—and on the other, in their

A

MANUAL OF CHEMISTRY;

CONTAINING

THE PRINCIPAL FACTS OF THE SCIENCE, ARRANGED IN THE ORDER IN WHICH THEY ARE DISCUSSED AND ILLUSTRATED IN THE LECTURES AT THE ROYAL INSTITUTION OF GREAT BRITAIN.

BY

WILLIAM THOMAS BRANDE,

Secretary of the Royal Society of London; Fellow of the Royal Society of Edinburgh; Professor of Chemistry in the Royal Institution of Great Britain; Professor of Chemistry and Materia Medica to the Society of Apothecaries of the City of London; Honorary Member of the Literary and Philosophical Society of New York; and of the Physico-Medical Society of Erlangen.

LONDON:

JOHN MURRAY, ALBEMARLE-STREET.

1819.

PLATE III

multifarious bearings upon the sister sciences and upon the useful arts, have been received."

His publications were numerous and, at the time, considered among the more important scientific works. His *Manual of Chemistry* (Plate III) went through seven editions and was translated into French, German and Italian. It has been described as "One of the most important text-books of the day", "One of the most popular in the English language." A very useful bibliography of his writings has been compiled by Mr. A. J. Horne, former Assistant Librarian of the Royal Institution.

This brief account has only provided an introduction to the life and work of one who deserves to be better known. It may be true that he left behind him no important original work but his knowledge of chemistry was accurate and extensive with a strong emphasis on the experimental rather than the speculative. There are many indications that his powers as a lecturer were considerable and as more material comes to light, one feels that his influence on science education in the early part of the century will be found to be widespread.

Of his great service to the Royal Institution there can be little doubt and as we take our leave of a forgotten worthy let him take his leave of us in the words with which he bade the members of 1852 farewell:

"Looking personally at the Royal Institution, I revere it, as my *alma mater*, where as a schoolboy I listened to the fruitful eloquence of Davy, and afterwards partook of his acquaintance and friendship; where I acquired the patronage of Sir Joseph Banks; where I was singled out by Wollaston as his successor in the secretaryship of the Royal Society; where I came into the frequent contact of the chiefs of science, and of literature and art; where Faraday became my pupil, colleague and friend. These, I assure you, are only a very few of the proud and pleasing reminiscences which accompany me from this place; and they are unsullied and unalloyed; they have never been clouded, tainted, or embittered. I again, therefore, thank you for all your partiality and kindness; and in gratitude to Providence, in whose hands are all the issues of our lives, I respectfully beg you to accept my affectionate farewell." (*Proc. Roy. Instn.*, 1852, **1**, 168-9).

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